IEC 62977-3-7

Edition 1.0 2022-01

INTERNATIONAL STANDARD

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Electronic displays –
Part 3-7: Evaluation of optical performance – Tone characteristics

IEC 62977-3-7:2022-01(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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Electronic displays –
Part 3-7: Evaluation of optical performance – Tone characteristics

INTERNATIONAL
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ICS 31.120

ISBN 978-2-8322-1070-7

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ELECTRONIC DISPLAYS –

Part 3-7: Evaluation of optical performance – Tone characteristics

FOREWORD

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

Draft	Report on voting
110/1371/FDIS	110/1397/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/standardsdev/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- withdrawn,
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INTRODUCTION

Images as formed by electronic displays have lateral variations of for example hue, saturation and intensity of visual stimuli. For displays of gradual smooth transitions no unwanted contours and no quantization artefacts should be visible. Therefore, the displays should render the required gradation of an image through tone reproduction. Tone is the variation in luminance, ideally with constant hue and saturation, at (r, g, b) input $(n, 0, 0)$, $(0, n, 0)$, $(0, 0, n)$, and (n, n, n), respectively, where n:{0, 1,…N}, and $N + 1$ is the number of quantization levels. Similarly, colour saturation tone is defined as the luminance variation, ideally with constant hue, but with varying saturation of the input (= 1 – min (r, g, b) / max (r, g, b)), for input (N, n, n), (n, N, n), and (n, n, N). Tone can also be defined for complementary colour (r, g, b) input $(0, n, n)$, $(n, 0, n)$, $(n, n, 0)$ and (n, N, N), (N, n, N), and (N, N, n), respectively. This is conceptually shown in Figure 1 which is the hue saturation lightness/intensity (HSL or HSI) model with RGB inputs for single colour tone, grey tone and colour saturation tone signal, where the lightness is defined as 0,5 × ((max (r, g, b) + min (r, g, b))). Note that this colour space is different from the device RGB colour space. Grey and RGB tone reproduction, and their additive relation, are fundamental optical properties of displays since they affect the fidelity with which colour is rendered from the input code values.

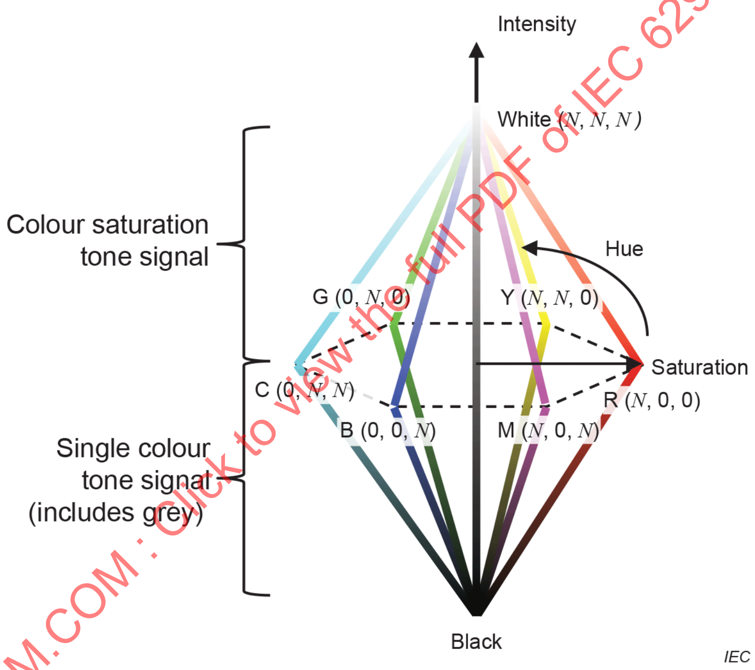


Figure 1 – Hue saturation lightness (HSL) colour model

In contemporary displays, nonlinear transformations into perceptually equidistant spaces are required to reduce visual artefacts while maintaining data economy. Also, the transformations linearize the opto-electrical transfer function, the nonlinearity of which is beneficial for reduction of artefacts such as quantization noise, banding, contouring, as well as for quantization efficiency.

The variation of electro-optical transfer functions (EOTFs) with viewing direction introduces further complications. The resulting impact omnidirectional image quality is more multifaceted compared to the viewing direction dependence of contrast, peak luminance, and colour of a limited number of patches.

This document describes methods for the measurement of EOTF and evaluation, and points out necessary precautions and diagnostics. The document is a reference for forthcoming standards to make the work of the involved experts more efficient and to avoid duplication of efforts.

ELECTRONIC DISPLAYS –

Part 3-7: Evaluation of optical performance – Tone characteristics

1 Scope

This part of IEC 62977 specifies the standard measurement and evaluation of optical performance for grey and colour tone reproduction of electronic displays under darkroom conditions. This document describes the measuring methods and evaluation of tone rendering of neutral grey, primary and secondary input colours. This document applies to displays with unbounded input signals.

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 TS 62977-3-1:2019, *Electronic displays – Part 3-1: Evaluation of optical performances – Colour difference based viewing direction dependence*

IEC 62341-6-3, *Organic light emitting diode (OLED) displays – Part 6-3: Measuring methods of image quality*

IEC 61966-2-1, *Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB*

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 http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
electro-optical transfer function
EOTF
nonlinear decoding
variation of the optical output of electronic visual displays in terms of for example luminance and chromaticity, as a function of the input signals

Note 1 to entry: The input signals could be R, G, B, C, M, Y, and grey for (r, g, b) input (n, 0, 0), (0, n, 0), (0, 0, n), (0, n, n), (n, 0, n), (n, n, 0), and (n, n, n), respectively, where n:{0,1,…N}, and $N + 1$ is the number of quantization levels per primary colour.

Note 2 to entry: The EOTFs for the C, M and Y inputs are optional.

Note 3 to entry: Generally, nonlinear decoding is the reciprocal of nonlinear encoding, but custom decoding is also available in many display products ("gamma" pre-sets).

3.1.2
nonlinear encoding [4], [7][1]
signal transform mostly expressed by a combination of a linear function for low input values and a power function with a single exponent above a certain level of input values as an opto-electrical transfer function (OETF) [4]

Note 1 to entry: It is used in image acquisition devices such as digital cameras for mapping scene luminance to digital code values prior to encoding, transmission, and/or compression.

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.

Note 3 to entry: The reason for the linear transformation for low input values is that the steepness of the power function is too close to zero (infinite), leading to artefacts (e.g. excessive noise).

3.1.3
display gamma
exponent of the power function specifying the target EOTF of a display

Note 1 to entry: Deviations from the ideal power function are possible and should be specified.

Note 2 to entry: Generally, the display gamma value is calculated from an EOTF with the luminance of the black level subtracted (de-biasing). Gamma is only defined if the de-biased EOTF obeys a power law, the exponent of which is the gamma. The gamma value of an ideal display is the same for R, G, B, C, M, Y and grey tone.

3.1.4
colour saturation tone function
variation of the optical output of electronic visual displays in terms of for example luminance and chromaticity, as a function of input signals with at least one RGB input kept at its maximum value and the remaining R, G or B inputs being varied and of equal value

Note 1 to entry: An ideal display renders constant colorimetric hue for the inputs.

Note 2 to entry: When the luminance at maximum saturation is subtracted from the colour saturation tone function (bias correction), and the resulting function obeys a power law, its exponent is called colour saturation gamma.

Note 3 to entry: The input signals could be R, G, B, C, M, and Y for (r, g, b) input (N, n, n), (n, N, n), (n, n, N), (n, N, N), (N, n, N), and (N, N, n), respectively, where n:{0,1,…N}, and $N + 1$ is the number of quantization levels per primary colour.

1 Numbers in square brackets refer to the Bibliography.

3.1.5
display bit depth
number of quantization levels, assuming binary-encoded levels

Note 1 to entry: It is the number of display bits or $\log_2$[number of addressable shades] in the tone rendering.

Note 2 to entry: The actual number of renderable shades is often reduced when white balancing is done by gain control [4], [7].

Note 3 to entry: Display colour depth is the sum of the bit depths of the rendered primary colours (RGB). Primary colours can have different bit depths, for example 5-, 6- and 5-bit RGB depth for 16-bit colour depth.

3.1.6
tone additivity function
sum of the R, G, and B tones divided by the grey tone

Note 1 to entry: An ideal display has unity additivity for all inputs.

3.1.7
unbounded input signal
input signal for which there is neither any host-side colour management nor any handshaking taking place between the host and the DUT

3.2 Abbreviated terms

ABC	automatic brightness control
ALL	average light level
ALS	ambient light sensor
APL	average picture level
CIELAB	CIE 1976 $L^*a^*b^*$ colour space
CMY	cyan, magenta, and yellow
DUT	device under test
EOTF	electro-optical transfer function
GOGO	gain-offset-gamma-offset
HSI	hue saturation intensity (device dependent colour space, also called HSL (hue saturation lightness))
JND	just noticeable difference
LMD	light measuring device
OETF	opto-electrical transfer function
OOTF	opto-optical transfer function
RGB	red, green, and blue
RGBCMY	red, green, blue, cyan, magenta, and yellow
SLET	stray light elimination tube
sRGB	a standard RGB colour space as defined in IEC 61966-2-1 (sRGB has the same colour gamut as the gamut of Recommendation ITU-R BT.709 [11])

4 Standard measuring equipment

4.1 Video signal generator

A digital video signal generator or a computer with digital RGB outputs, each with at least 8-bit depth, shall be used. The signal bit depth supported by the DUT shall be reported according to Clause 7.

4.2 Measuring equipment and conditions

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

4.3 Test equipment setup

The setup of a non-close-up light measuring device (LMD) is shown in Figure 2 in the case of a perpendicular direction measurement. The optical axis of the LMD shall be centred on the screen and perpendicular to the plane of the display screen. The general conditions of the measuring equipment, such as angular aperture, shall follow IEC 62977-2-1. A close-up type LMD as shown in Figure 3 can be used only for measurements perpendicular to the DUT. A close-up LMD shall have input optics with a well-defined measurement field angle similar to that of non-close-up LMDs. The accuracy of the close-up type LMD shall be verified by a non-close-up spectroradiometer.

The measuring layout for viewing directional measurement shall be applied by moving the LMD or by rotation of the display in the horizontal viewing direction as shown in Figure 4a) and b), where a vertical arrangement for a vertical viewing direction is also possible. Alternatively, the spherical coordinate system as shown in Figure 4c) shall be applied (refer to IEC TS 62977-3-1:2019, 6.1, and IEC 62977-2-1:2021, 5.6 and 6.10). The directional measurement shall be done with a non-close-up measurement.

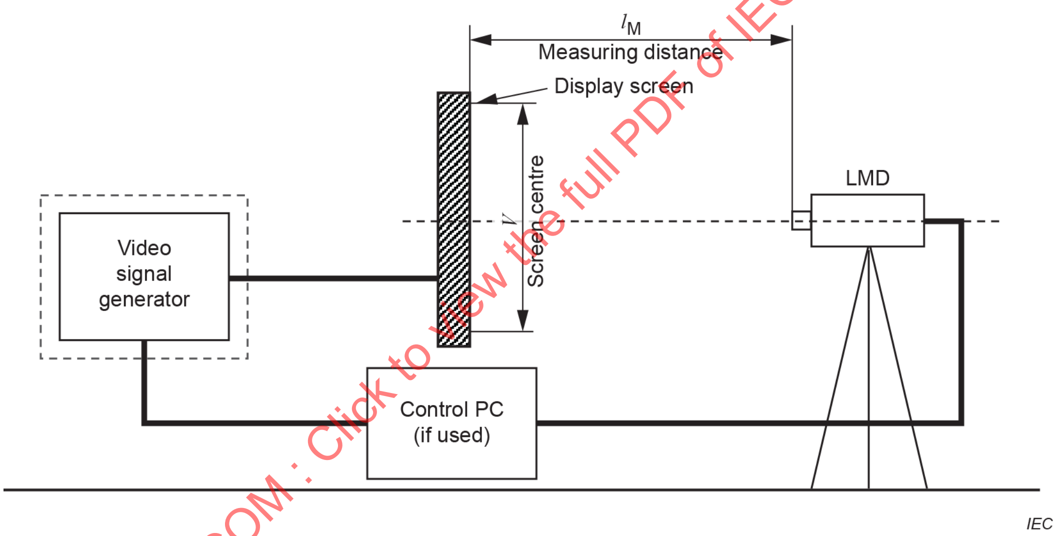


Figure 2 – Measuring layout for non-close-up measurement

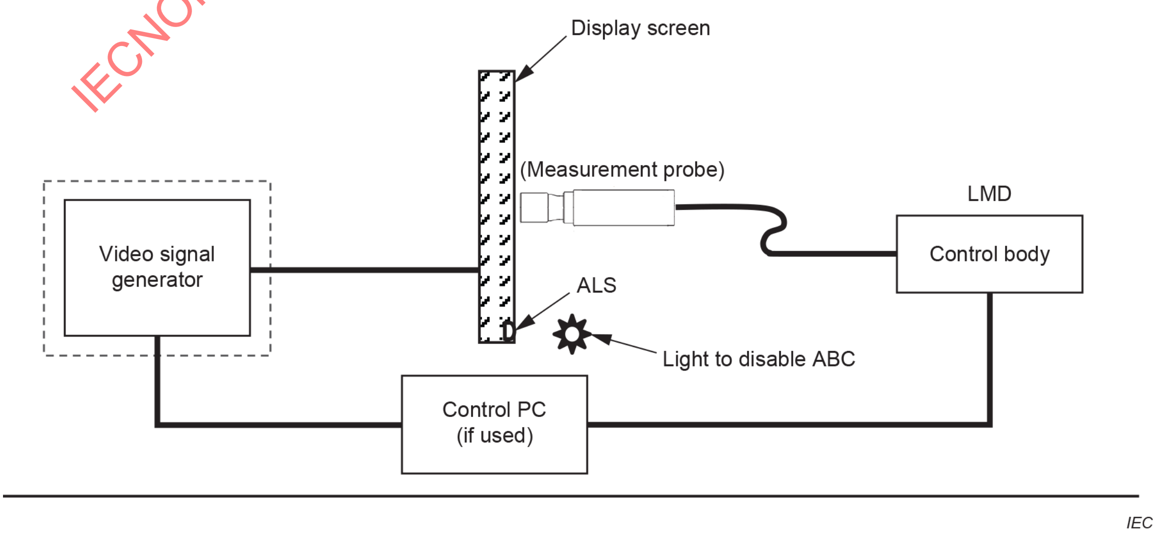
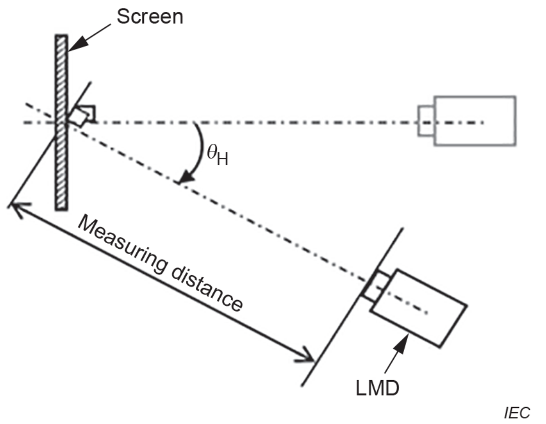
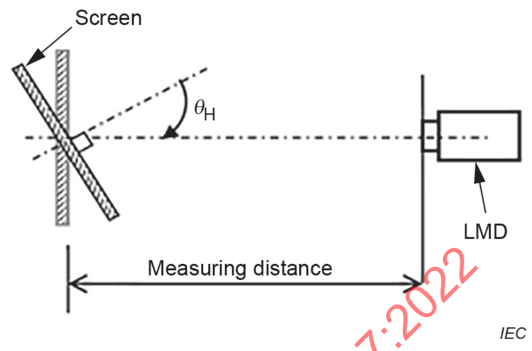


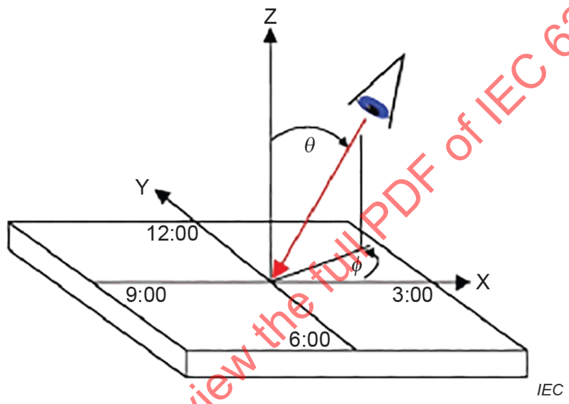
Figure 3 – Measuring layout for close-up type LMD



a) **Measurement by moving the LMD (top view)**



b) **Measurement by rotating the DUT (top view)**



c) **Measurement in spherical coordinate system**

Figure 4 – Setup for viewing directional measurements

5 Standard measuring conditions

5.1 Standard measuring environmental conditions

Refer to IEC 62977-2-1:2021, 5.1, where the standard environmental conditions 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 Standard measuring darkroom conditions

Refer to IEC 62977-2-1:2021, 5.2.

5.3 Adjustment of display

The display shall be warmed up prior to taking measurements. 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 may need 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 for a given display image.

The standard operating conditions of the display shall be set by the following sequence.

a) Initialized status

   The DUT shall be set to the factory settings. Other modes (including white coordinates such as D65) may be selected after power-on and the selected mode shall then be noted in the test report and used throughout all measurements.

b) Adjustment of ambient light control (if applicable)

   Turn off the ABC by disabling the ALS. If it cannot be disabled, place a shielded light source in front of the ALS that provides an illuminance of at least 300 lx at the surface of the ALS. Make sure that the darkroom conditions are maintained while the shielded light source is on. The details of the ABC-disabling light source shall be noted in the report.

c) Adjustment of protective and energy saving settings

   Turn off all customer functions for power management and DUT protection and keep them off throughout the measurement. If such functions are turned on automatically when continuously displaying test images, reset or change the test pattern until such functions are turned off again. Some displays adapt to content to save power and/or render the image in special ways but these functions shall remain at their default settings.

d) Adjustment of aspect ratio

   The test pattern shall be displayed in the aspect ratio identical to that of the display screen without over scan.

5.4 Starting conditions of measurement

The display system shall be warmed up prior to taking measurements according to IEC 62977-2-1:2021, 5.3.3.

5.5 Standard test pattern

5.5.1 General

Figure 5 schematically shows the tonal range of the measurements in the device-dependent colour space RGB. In terms of the input signal, the tone measurements can be divided into:

1) single colour (or two colours with identical value) input tone,
2) constant single colour (or two colours) at maximum input adding the tones of the two other colours with identical value (or the other colour tone), respectively, and
3) grey tone where RGB values are identical.

Numbers 1) and 3) are called RGBCMY and grey tonal curves, respectively, whereas number 2) is called colour saturation tonal curves, whose range is from fully saturated RGBCMY colour to white.

If there is no specific comment, all measured and calculated data are recommended to have at least 4-digit significant figures.

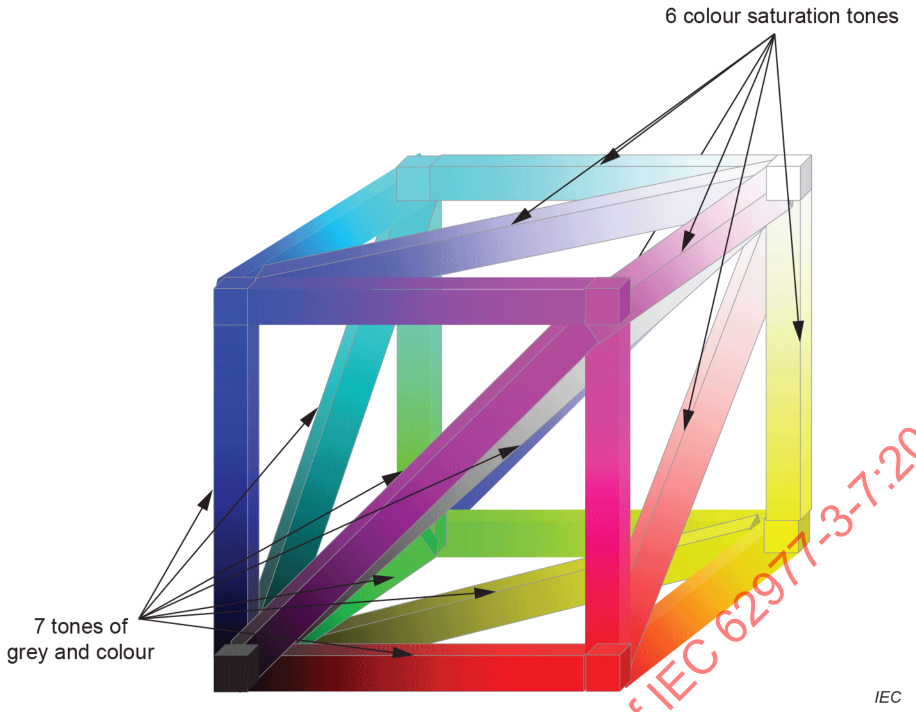


Figure 5 – RGB input ranges for 7 tones and 6 colour saturations

5.5.2 Test pattern for grey and colour tone measurement

Tone is directly related to the DUT luminance, and the power consumption generally increases with luminance. Some displays have a limited power supply and/or dimming/boosting functions [19], which means that luminance can depend on the APL [20]. In that case, the power consumption might be proportional to the ALL of average luminance on the screen.

In the grey and colour tone measurements, the input APL is kept constant at 24,7 % using a test pattern with complementary colour blocks (see Figure 6 to Figure 8). The RGB values of these blocks, V_{Q}', are complementary to the RGB values of the centre test patch,

$$V'_Q = \left(2^N - 1 - V_Q\right) \qquad (1)$$

where

Q is {R, G, B};

N is the bit depth;

V_{Q} is the signal value of colour Q of the centre test patch.

For the calculation of APL, the colour box pattern is converted as shown in Figure 8. The APL of Figure 8 corresponds to 5 white boxes that are white, R + C, G + M, B + Y, and centre + complementary colour block. The APL of the test pattern is therefore 24,7 % (= 5 × (2 / 9)^2).

While the pattern in Figure 6 and Figure 7 provides constant APL, it is also a potential source of stray light, particularly for larger APLs and when using a non-close-up LMDs. If stray light is a problem, a frustum or SLET shall be used.

The test pattern shall consist of 11 or 17 steps (n = 11 or 17) of equally spaced inputs (see IEC 62977-2-1:2021, Annex A). Some displays under some viewing conditions exhibit saturated and/or non-monotonic EOTFs. In such cases, more steps can be necessary to properly sample the EOTFs. Table 1 shows an example of input code values (V_i) of RGB for grey tone measurement.

Table 2 shows the input code values (V_i) of RGB for colour tone measurement for 8- and 10-bit cases and 11 and 17 levels. Some measurements can require a larger number of inputs.

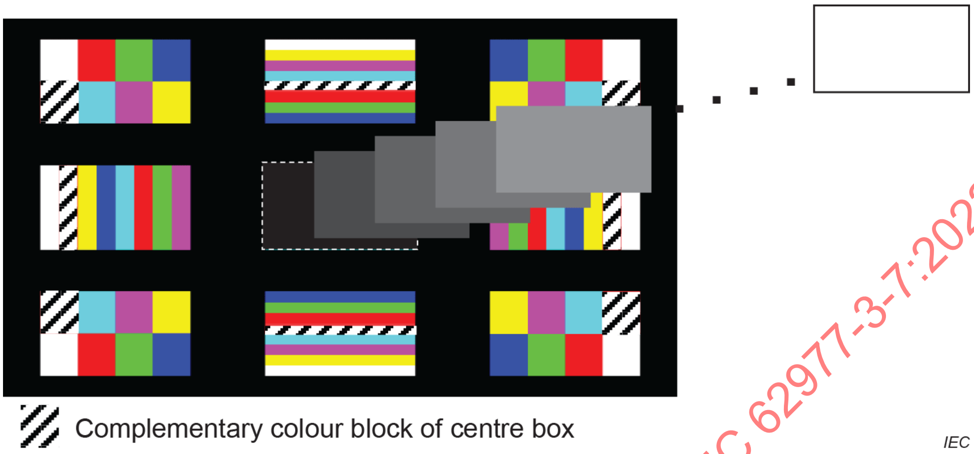


Figure 6 – Multi-colour pattern for grey tone measurement

Table 1 – RGB input level for 11 steps and 17 steps

Input no. (i)	11-step inputs (V_i)		17-step inputs (V_i)	
	10 bits	8 bits	10 bits	8 bits
1	0	0	0	0
2	102	25	63	15
3	205	51	127	31
4	307	76	191	47
5	409	102	255	63
6	511	127	319	79
7	613	153	383	95
8	716	178	447	111
9	818	204	511	127
10	920	229	575	143
11	1 023	255	639	159
12			703	175
13			767	191
14			831	207
15			895	223
16			959	239
17			1 023	255

Table 2 – RGB input composition for grey tone and colour tone

Tone colour	Input code		
	R'	***G'***	***B'***
Grey	V_i	V_i	V_i
Red	V_i	0	0
Green	0	V_i	0
Blue	0	0	V_i
Cyan	0	V_i	V_i
Magenta	V_i	0	V_i
Yellow	V_i	V_i	0

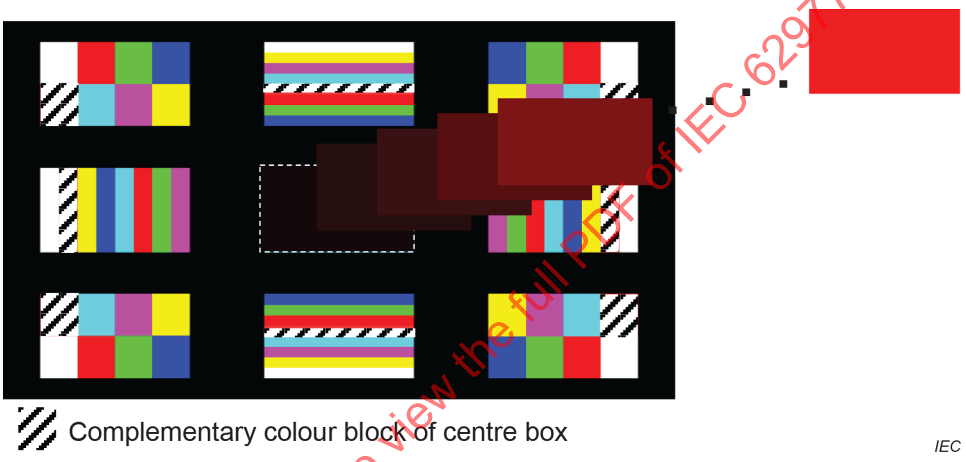


Figure 7 – Multi-colour pattern for colour tone measurement (example for red tone)

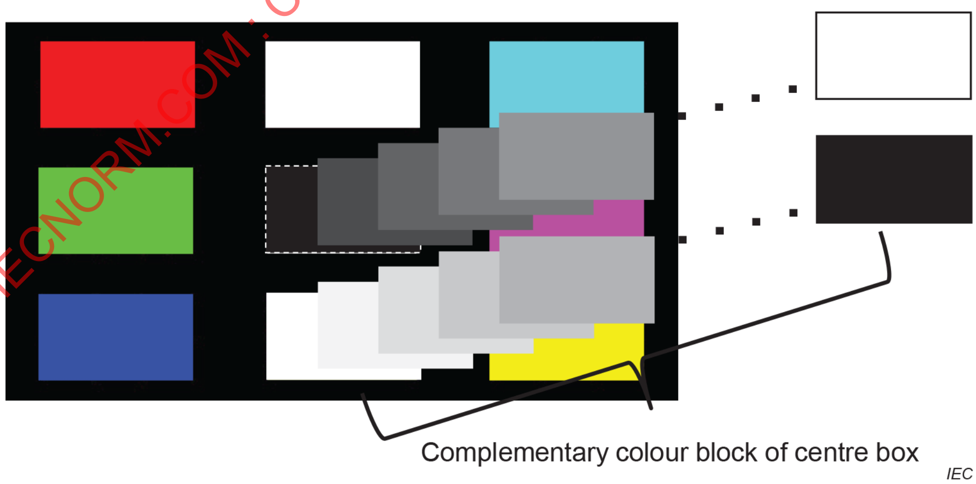


Figure 8 – Equivalent pattern for APL calculation of multi-colour pattern (example for grey tone)

5.5.3 Test pattern for colour saturation tone measurement

The constant APL pattern shall be used also for the colour saturation tone measurement. The centre box of the pattern shall be changed in 11, 17, or more steps depending on the required accuracy and considering the colour saturation tone function shape. The standard test pattern for the measurement shall be as shown in Figure 9. When measurement by a non-close-up LMD is affected by stray light from the background tiles, a frustum or SLET shall be used.

Table 1 and Table 3 show the input code values (V_i) and input colour composition for the colour saturation tone measurement.

Table 3 – RGB input composition for colour saturation tone

Saturation colour	Input code		
	R'	*G'*	*B'*
Red	255	V_i	V_i
Green	V_i	255	V_i
Blue	V_i	V_i	255
Cyan	V_i	255	255
Magenta	255	V_i	255
Yellow	255	255	V_i

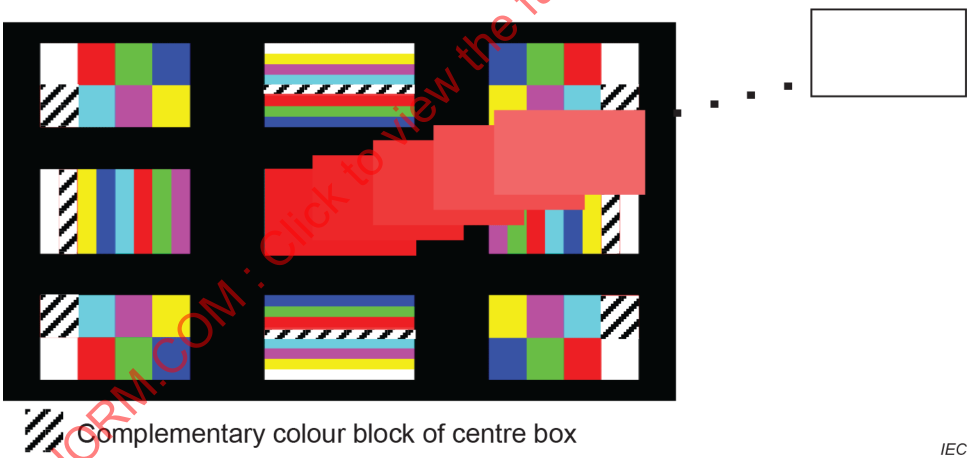


Figure 9 – Multi-colour pattern for colour saturation tone measurement (example for red saturation)

6 Measurements and evaluation of tone characteristics

6.1 EOTF and display gamma for grey and colour tone

6.1.1 Measured data

If 11 steps are sufficient and colour gamut volume already is measured according to IEC 62977-2-1, no further measurement of RGBCMY is necessary. However, an additional 11-point measurement of the grey tone shall be performed using the input levels in Table 4. If the EOTF obeys a power law, the display gamma can be calculated according to the methods in 6.1.3 to 6.1.5. If the EOTF does not obey a power law, steps e) and f) in 6.1.2 do not apply, and it is then recommended that the number of steps be increased from 11 or 17.

Table 4 – Selected measured data for display gamma from the 602-point measurement

Input no. (i)	Input level		Colour number in 602 inputs (see IEC 62977-2-1)					
	%	Code value (V_i)	*R*	*G*	*B*	*C*	*M*	*Y*
1	0	0	1	1	1	1	1	1
2	10	25	122	12	2	13	123	232
3	20	51	133	23	3	25	135	243
4	30	76	144	34	4	37	147	254
5	40	102	155	45	5	49	159	265
6	50	127	166	56	6	61	171	276
7	60	153	177	67	7	73	183	287
8	70	178	188	78	8	85	195	298
9	80	204	199	89	9	97	207	309
10	90	229	210	100	10	109	219	320
11	100	255	221	111	11	121	231	331

6.1.2 Measuring method

In many cases, the display luminance follows a power function of the input signal, where the exponent is called gamma. The tone reproduction of such a display would be explained and evaluated as follows:

$$L(V_i) = a(V_i - V_K)^\gamma + L_K \quad (2)$$

where

a is a constant,

V_K is the input level for black (normally, V_K = 0), and

L_K is the black luminance.

For the EOTF measurement, the contrast and brightness controls, if any, shall be set to their default values or disabled. The measurement shall be performed as follows:

a) Input the pattern of Figure 6 and Figure 7 with the required number of patches. If the boxes cause image sticking, a full black frame can be inserted between each input levels. The duration of the full black frame may have to be adjusted in order to eliminate image sticking.
b) Measure the luminance (or tristimulus values for colour tracking) at the screen centre perpendicularly to the display screen.
c) Measure in order from low to high luminance of the centre box.
d) Repeat the luminance measurements of colour patterns from black to maximum input of each RGB colour signal and optionally for CMY.
e) If R^2 of the linear regression formula is over 90 % in the log-log plot (see 6.1.4), the tone function can be considered to be a power function. In that case, calculate the gamma value by linear regression.
f) Report the average gamma for each pattern. If necessary, report the other gamma value such as log-log gamma.
g) Report the measured EOTFs by plotting the result and tabulating the values.

6.1.3 Average gamma calculation

Gamma value is a useful, single-value parameter that can be used to estimate the non-linearity of an EOTF that obeys a power law. It can also be used to calculate the gamma accuracy with respect to a target gamma.

When calculating the gamma from a power law EOTF, the offset by the black-state luminance shall first be subtracted (de-biasing). The display gamma value (power law exponent) can be calculated by taking the logarithm of the de-biased luminance function. The average gamma is then calculated by averaging the gamma values of each input (refer to IEC 61988-2-6 [20] and IEC 62341-6-4 [10]) [2], [4], [5]. Among the gamma calculation methods, this method gives the best linearity, that is, there is a strong correlation between a smaller gamma and average image luminance.

$$\gamma_{\mathrm{A,Q}} = \frac{1}{n-2}\sum_{i=2}^{n-1}\gamma_{i,\mathrm{Q}} = \frac{1}{n-2}\sum_{i=2}^{n-1}\frac{\log\left(L\left(V_{i,\mathrm{Q}}\right)-L_K\right)_{\mathrm{norm}}}{\log\left(V_{i,\mathrm{Q}}-V_K\right)_{\mathrm{norm}}} \quad (3)$$

where

$\gamma_{\mathrm{A,Q}}$	is the average gamma,
Q	is W, R, G, B, C, M or Y,
n	is the number of inputs (from 1st to nth), and $L(V_{1,Q}) = L_{\mathrm{K}}$,
$(L(V_{i,\mathrm{Q}}) - L_{\mathrm{K}})_{\mathrm{norm}}$	is the normalized value of the luminance measured for input i, $(L(V_{i,\mathrm{Q}}) - L_{\mathrm{K}})$ / $(L(V_{n,\mathrm{Q}}) - L_{\mathrm{K}})$, and
$(V_{i,\mathrm{Q}} - V_{\mathrm{K}})_{\mathrm{norm}}$	is the normalized value of the code value for input i.

Due to the smaller luminance range (smaller slope of the EOTF), the gamma values calculated from the lower input values have a smaller deviation from the mean gamma value compared to gamma values calculated from the higher input values. Even when the EOTF is not exactly following a power law, it shall at least be monotonic in order to use this calculation method. Data points which make the EOTF non-monotonic have to be discarded and the accuracy of the calculated average gamma is then reduced. When evaluating the luminance saturation with signal processing between two neighbouring levels, the interlevel gamma can be available (see Annex A).

Provided that the EOTF is a power function (see 6.1.4), the standard deviation of the gamma values for each input can be used to check how well the DUT gamma matches the power function. The standard deviation of the averaged gammas is calculated according to Formula (4).

$$SD_{\mathrm{Q}} = \sqrt{\frac{\sum_{i=2}^{n-1}\left(\gamma_{i,\mathrm{Q}} - \gamma_{\mathrm{S}}\right)^2}{n-3}} \quad (4)$$

where

Q is W, R, G, B, C, M or Y.

Gamma accuracy can be calculated by comparing the measured gamma with the target gamma:

$$\sigma_\gamma = \frac{\gamma_S - \gamma_{A,Q}}{\gamma_S} \times 100(\%) \quad (5)$$

where

σ_γ is the gamma accuracy,

Q is W, R, G, B, C, M or Y, and

γ_S is the target gamma value (for example, 2,2 for sRGB or 2,4 for Recommendation ITU-R BT.1886 [13]).

Recommendation ITU-R BT.1886 assumes that the black luminance is 0 whereas the standard EOTF includes the non-zero black level of the display system [13].

Table 5 shows an example of an average gamma calculation. In Figure 10, it is shown that an average gamma value larger than 2,2 results in lower luminance. From Table 5 and Figure 10 it can be seen that the power law EOTF with an average gamma value of 2,755 best matches the EOTF with a gamma of 2,8 at input levels where the two gammas are close (input nos 10 to 12).

Table 5 – Example of average gamma calculation

Input no. (i)	Input level (V_i)	L (cd/m^2)	Gamma value
1	0	0,29	-
2	15	0,85	2,247
3	31	2,81	2,309
4	47	6,67	2,326
5	63	12,70	2,338
6	79	20,00	2,394
7	95	28,97	2,462
8	111	39,49	2,547
9	127	51,89	2,644
10	143	68,31	2,709
11	159	86,55	2,815
12	175	108,80	2,922
13	191	135,23	3,052
14	207	166,27	3,237
15	223	205,77	3,442
16	239	253,73	3,885
17	255	326,29	-
Average gamma		2,755	
Gamma standard deviation		0,477 3	
Gamma accuracy (versus gamma 2,2)		74,76 %	

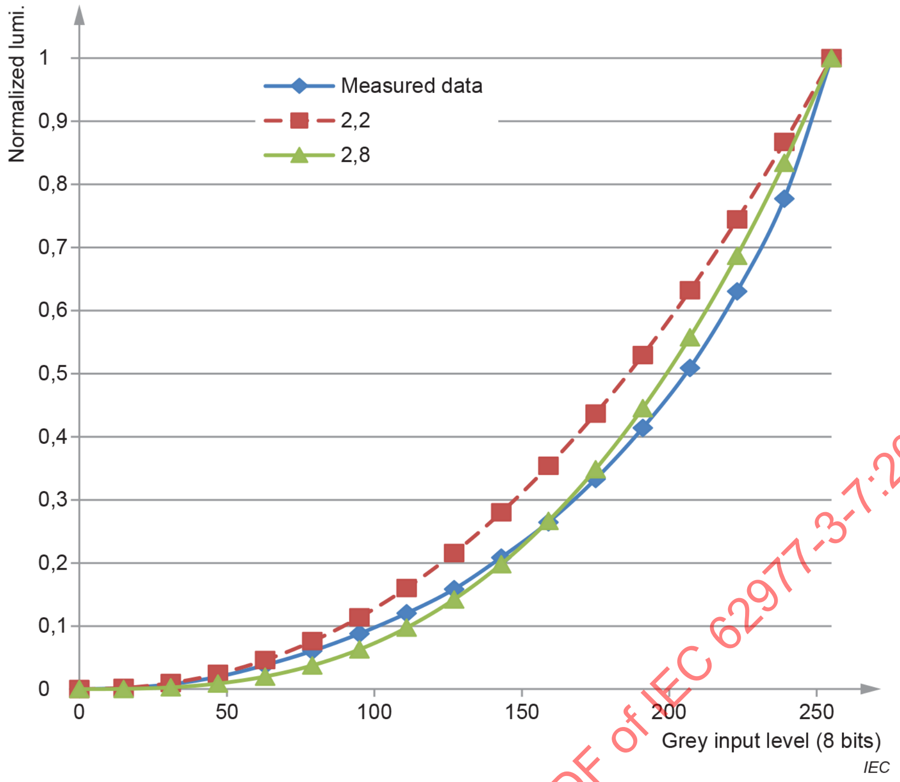


Figure 10 – Example of a measured EOTF compared with ideal power law curves

6.1.4 Log-log gamma calculation

As explained in 6.1.3, provided that the EOTF is a power function, the log function can yield the gamma value. The gamma value can be also estimated by the slope of a linear regression of each measured point (refer to IEC 62341-6-3) [1], [9]. For the linear regression, the following log-log formula from Formula (2) is rewritten as a linear formula, $y = mx + b$. In this formula, the slope m corresponds to the value of the log-log gamma (γ) [16]. When performing the linear regression, black input data for the y-axis intersection is excluded as follows:

$$\log\left[L(V_i)\text{-}L_{\mathrm{K}}\right] = \gamma \log(V_i - V_{\mathrm{K}}) + \log(a) \tag{6}$$

Table 6 shows an example of log-log gamma calculation with the same data as in Table 5. Figure 11 shows the result of a linear regression of the data in Table 6. The y value in Figure 11 is slightly different from the logarithm of the luminance in Table 6 because the regression in Figure 11 is an approximated line to estimate the luminance. If R^2 of the log-log linear regression is larger than 0,90, the EOTF can be considered to be a power function. If R^2 < 0,90, gamma shall not be used and the EOTF shall instead be tabulated.

Table 6 – Example of log-log gamma calculation

Input no. (i)	Input level (V_i)	L (cd/m²)	y value ($y = mx + b$)
1	0	0,29	-2,792
2	15	0,85	-0,252
3	31	2,81	0,400
4	47	6,67	0,805
5	63	12,70	1,094
6	79	20,00	1,295
7	95	28,97	1,458
8	111	39,49	1,593
9	127	51,89	1,713
10	143	68,31	1,833
11	159	86,55	1,936
12	175	108,80	2,035
13	191	135,23	2,130
14	207	166,27	2,220
15	223	205,77	2,313
16	239	253,73	2,404
17	255	326,29	2,513
b = log(a)	-2,792	log-log gamma	2,204

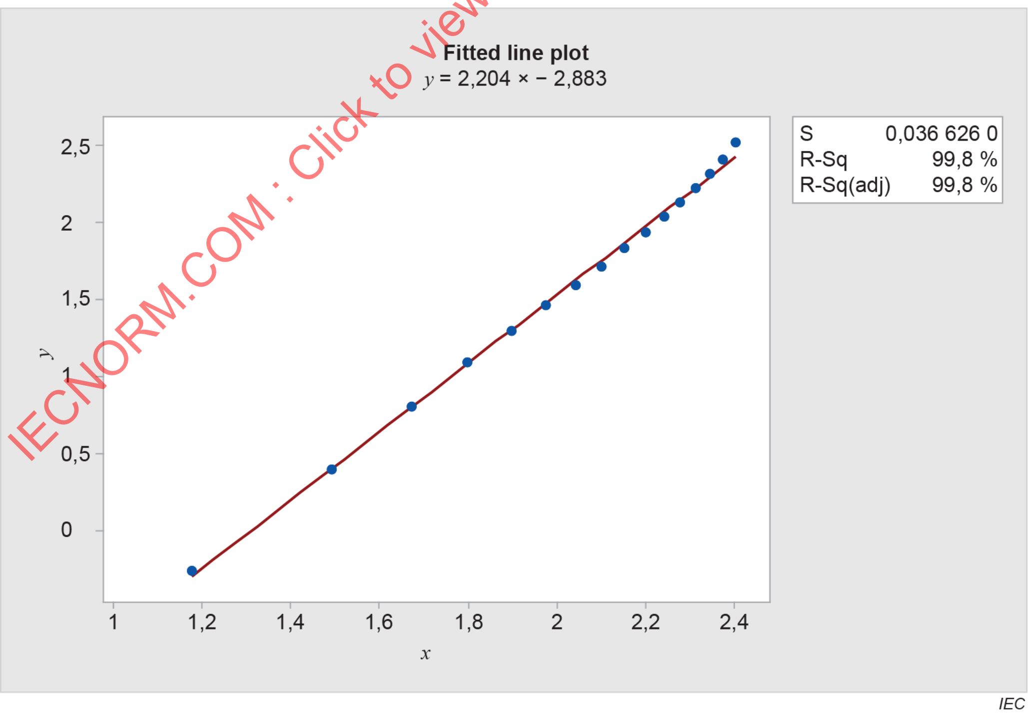


Figure 11 – Example of linear regression formula and plot for log-log gamma

While the input signals are equally spaced in the range 0 to 255 (case of a bit depth of 8), the x values in a log-log graph are not. The x values of the log-log gamma graph have an 80 % wider range in the lower half compared to the upper half, so the log-log gamma value is dominated by the slope of the lower input range. On the other hand, the model fitting gamma (refer to IDMS Chapter 6 [1]) by the GOGO model is dominated by the higher input range because the higher input generally causes the bigger difference in luminance. Therefore, the model fitting gamma is seldom used in consumer products with large gammas, such as TVs. Another method to calculate gamma is to perform a least-square curve fitting to a power function using non-linear regression or the Levenberg–Marquardt algorithm.

6.1.5 Grey scale tracking accuracy

For the evaluation of constant chromaticity of grey or RGBCMY tones, the measured data in 6.1.3 or the 602-point data can be used. In the case of 6.1.3, the chromaticity coordinates and luminance of each patch shall be measured or calculated from measured tristimulus values XYZ. From the measured data for each level input, the colour tracking accuracy shall be evaluated by the CIE colour difference formula ΔE_{00} shown in Formula (7). It expresses the average colour difference between the colour at full input and the tone levels. For the detail of formula ΔE_{00} [3], refer to IEC 62977-3-1.

$$\begin{aligned} \Delta E_{00} &= \frac{1}{n-2}\sum_{i=2}^{n-1} \Delta E_{00\_i} \\ &= \frac{1}{n-2}\sum_{i=2}^{n-1} \sqrt{\left(\frac{\Delta L'_i}{S_{L_i}}\right)^2 + \left(\frac{\Delta C'_i}{S_{C_i}}\right)^2 + \left(\frac{\Delta H'_i}{S_{H_i}}\right)^2 + R_{T_i}\left(\frac{\Delta C'_i}{S_{C_i}}\right)\left(\frac{\Delta H'_i}{S_{H_i}}\right)} \end{aligned} \quad (7)$$

where

ΔE_{00_i} is the grey scale tracking accuracy, and

n is the number of steps used in the EOTF measurement.

Report the average (grey scale tracking accuracy), minimum, and maximum colour difference ΔE_{00_i}.

6.1.6 Directional EOTF

Generally, the optical characteristics of displays depend on the viewing direction. Due to the vantage point of the human eye when watching two-dimensional displays, the viewing direction is one of the inevitable display properties as well as the viewing direction caused by the viewer's position. As the display resolution becomes higher, and the viewing distance becomes closer [8], the viewing directional characteristics become more important for constant image quality up to the screen corner that is evaluated by the vantage point measurement. The image quality largely depends on the EOTF, which in turn depends on the viewing direction (see IEC 62341-6-3, IEC TS 62977-3-1 and [1]).

The measurement of colour shift and gamma dependence on the viewing direction for a set of patches is described in IEC TS 62977-3-1. However, these patches are not sampled uniformly on the EOTFs, and gamma is calculated with the log-log method in which the lower input levels dominate. The measurement and evaluation of EOTF constancy by the viewing direction is done in the same way as in 6.1 but reported for several horizontal and vertical viewing directions. Provided that the EOTFs are power functions, Formula (3) shall be used for calculating the gamma value at each direction. If the EOTFs are not power functions, the EOTF shall be tabulated and plotted for each viewing direction.

The directional EOTF/gamma shall be measured for the grey for every 15° inclination (θ) angle up to ±60° depending on the application. For example, TV and monitor applications may not require angles larger than θ = ±30° in the vertical direction (ϕ = 90° or 270°). The measurement setup in Figure 4 shall be used (refer to IEC 62977-2-1:2021, 6.10 and 7.10 and IEC TS 62977-3-1:2019, 6.1). For the diagonal direction measurement, the azimuthal angle ϕ is 45° or 225°.

Provided that the EOTFs are power functions, directional gamma constancy shall be evaluated by Formula (8) (refer to IEC 62341-6-3 and [1]).

$$\sigma_\theta = \frac{|\gamma_{A,0} - \gamma_{A,\theta}|}{\gamma_{A,0}} \times 100\,(\%) \tag{8}$$

where

σ_θ is the directional gamma distortion,

$\gamma_{A,0}$ is the average gamma at the normal direction, and

$\gamma_{A,\theta}$ is the average gamma at the inclination angle θ in the horizontal (ϕ = 0°, 180°) or vertical (ϕ = 90°, 270°) direction.

6.2 Colour saturation tone accuracy

6.2.1 Measured data

This measurement is identical to that of the EOTF (see 6.1) except that other patches are used. If 11 steps are sufficient and colour gamut volume is already measured according to IEC 62977-2-1, no further measurement for the colour saturation tone is necessary. Table 7 shows the patches for an 11-point measurement.

Table 7 – Selected measured data for colour saturation tone function from the 602-point measurement

Input no. (i)	Input level		Colour number in 602 inputs (see IEC 62977-2-1)					
	%	Code value (V_i)	*R*	*G*	*B*	*C*	*M*	*Y*
1	0	0	221	111	11	121	231	331
2	10	25	332	432	522	441	341	422
3	20	51	343	443	532	451	351	423
4	30	76	354	454	542	461	361	424
5	40	102	365	465	552	471	371	425
6	50	127	376	476	562	481	381	426
7	60	153	387	487	572	491	391	427
8	70	178	398	498	582	501	401	428
9	80	204	409	509	592	511	411	429
10	90	229	420	520	602	521	421	430
11	100	255	431	431	431	431	431	431

6.2.2 Measuring method

If the colour saturation tone function obeys a power law, the colour saturation gamma can be calculated according to Formula (9) and the methods in 6.1.3 to 6.1.5. If the colour saturation tone function does not obey a power law, measure also the tone additivity function in 6.3.

$$L(V_i) = aV_i^{\gamma} + L_Q \tag{9}$$

where

a is a constant,

Q is R, G, B, C, M or Y, and

L_Q is the luminance of colour Q at saturation 100 % (V_i = 0).

If the measured data in IEC 62977-2-1 is not available, or if more than 11 steps are necessary, use the input values in Note 3 of 3.1.4. The measurement shall be performed as follows:

a) Input the pattern of Figure 9 for the required number of equidistant steps (for centre patch values, see 3.1.4).
b) Measure the luminance at the screen centre perpendicularly to the display surface.
c) Measure the C saturation tone in order from fully saturated cyan (G = B = 255) to white.
d) Repeat the luminance measurements for M saturation (R = G = 255), Y saturation (G = B = 255), and optionally for R, G, and B saturation.
e) Calculate the difference of luminance between R tone (G = B = 0) and C saturation tone (G = B = 255) excluding the offset luminance of full saturation.
f) Repeat the calculations for M, Y saturation tone, and optionally for R, G, and B saturation.
g) Report the evaluation result of the colour saturation tone accuracy with the tabulated and plotted values.

6.2.3 Evaluation of colour saturation tone accuracy

Colour saturation tone accuracy can be used to check the RGB independency for mixed colours. For the evaluation of colour saturation tone accuracy, compare the luminance values of the CMY colour saturation tone function (see 3.1.4) with the luminance of RGB tones, respectively. For this comparison, the luminance at fully saturated colour input shall be subtracted similarly to the subtraction of black luminance in the EOTF gamma calculation (see 6.1.3). In this case, theoretically, the colour tone and colour saturation tone shall show identical tone variation because both the luminance by input number 1 in Table 4 and Table 7 are excluded. The colour saturation tone accuracy is calculated as follows.

$$\sigma_{\mathrm{C,QC}} = \frac{1}{n-1}\sum_{i=2}^{n}\sigma_{i,\mathrm{QC}} = \frac{1}{n-1}\sum_{i=2}^{n}\left(1-\frac{\left|\left(L(V_{i,\mathrm{Q}})-L_{\mathrm{K}}\right)-\left(L(V_{i,\mathrm{QC}})-L_{\mathrm{QC}}\right)\right|}{L(V_{n,\mathrm{Q}})-L_{\mathrm{K}}}\right)\times 100 \quad (\%) \qquad (10)$$

where

$\sigma_{\mathrm{C,QC}}$ is the colour saturation tone accuracy of colour QC;

Q is R, G, B, C, M or Y;

QC is the complementary colour of Q, that is, C, M, Y, R, G or B, respectively;

n is the number of inputs (from 1$^{\mathrm{st}}$ to n^{th}), and $L(V_{n,\mathrm{QC}})$ = white luminance;

$L(V_{i,\mathrm{Q}})$ is the luminance measured for input number i of colour Q;

L_K is the black luminance.

Table 8 shows an example of colour saturation tone accuracy evaluation for cyan saturation that is R variation when G and B = 255. Figure 12 shows the colour saturation tone curve of Table 8.

Table 8 – Example of colour saturation tone evaluation (cyan saturation)

Input no. (i)	Input level (V_i)	Lumi.(cd/m²)				Abs($b-a$)	Colour saturation tone accuracy (%)
		$L(V_{i,\mathrm{QC}})$	$L(V_{i,\mathrm{QC}})-L_{\mathrm{QC}}$ (a)	$L(V_{i,\mathrm{Q}})$	$L(V_{i,\mathrm{Q}})-L_{\mathrm{K}}$ (b)		
1	0	257,8	0,00	0,07	0,00	0,00	
2	15	261,0	3,26	0,19	0,11	3,15	95,6
3	31	264,3	6,53	0,62	0,55	5,98	91,7
4	47	267,6	9,79	1,47	1,39	8,39	88,3
5	63	270,8	13,05	2,79	2,72	10,33	85,6
6	79	274,1	16,31	4,40	4,33	11,99	83,3
7	95	277,3	19,58	6,37	6,30	16,54	81,5
8	111	283,9	26,10	8,69	8,62	27,28	75,6
9	127	290,4	32,63	11,42	11,34	29,46	70,3
10	143	296,9	39,15	15,03	14,96	28,78	66,3
11	159	303,4	45,68	19,04	18,97	29,66	62,8
12	175	315,5	57,75	23,94	23,86	31,96	52,7
13	191	324,3	66,56	29,75	29,68	33,50	48,6
14	207	336,1	78,31	36,58	36,51	38,12	41,7
15	223	345,9	88,10	45,27	45,20	44,01	40,2
16	239	355,7	97,89	55,82	55,75	45,00	41,2
17	255	326,3	68,52	71,78	71,71	12,98	95,6
Colour saturation tone accuracy						Min	40,2
						Max	95,6
						Average	70,05

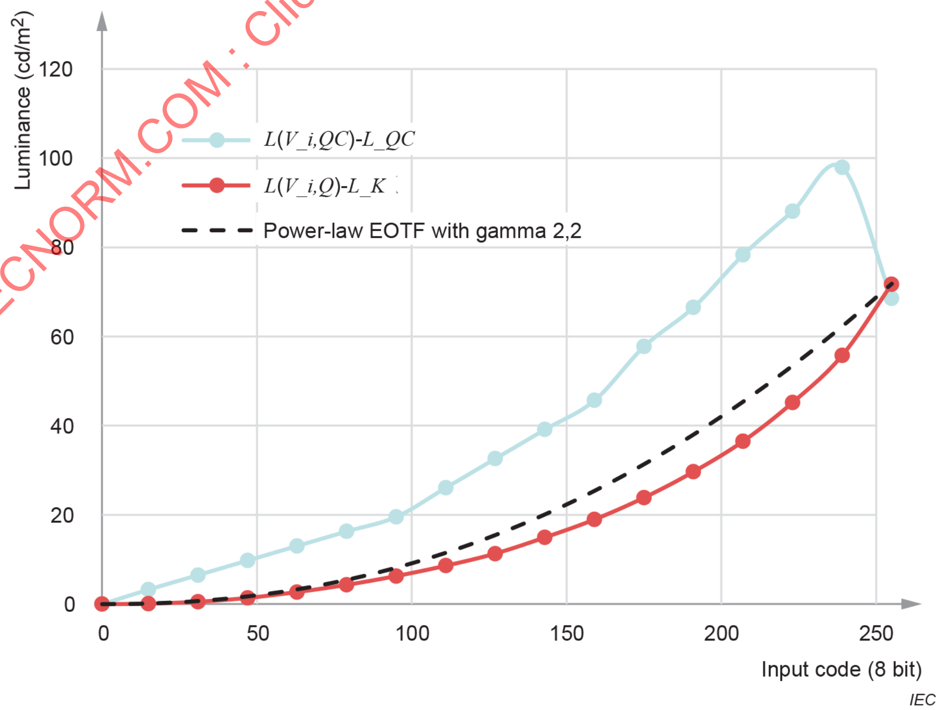


Figure 12 – Example of colour saturation tone evaluation

The average colour saturation tone accuracy of CMY colour is as follows, and it shall be reported with the colour saturation tone curve.

$$\sigma_{\mathrm{C}} = \frac{1}{3}(\sigma_{\mathrm{C,C}} + \sigma_{\mathrm{C,M}} + \sigma_{\mathrm{C,Y}}) \quad (11)$$

where

σ_{C} is the average colour saturation tone accuracy.

NOTE Colour saturation tone accuracy for RGB is optional.

6.3 Tone additivity function

This function is constructed from the already measured EOTFs and is used for identifying the grey values for which the luminance of unsaturated colours is higher compared to the case of an additive display. In displays for which the colour saturation tone functions (see 3.1.4) do not obey a power law, this cannot be judged only from the ratio of the colour saturation gamma and grey EOTF gamma. Also, tone additivity constancy indicates the absence of any EOTF clipping, even if the display is non-additive.

The tone additivity function is the relationship between the input grey value and the additivity as a display function implementing the tone additivity properties of input signal. The tone additivity of input grey level i is given by

$$A_i = \frac{L(V_{i,\mathrm{R}}) + L(V_{i,\mathrm{G}}) + L(V_{i,\mathrm{B}})}{L(V_{i,\mathrm{W}})} \quad (12)$$

where

$L(V_{i,\mathrm{Q}})$ is the luminance of colour Q at grey level i.

The tone additivity function is obtained by substituting input grey values in Formula (12).

Figure 13 (solid line) shows an example of tone additivity for a display for which the average colour saturation gamma (see 3.1.4) is 1,95, and its grey EOTF obeys a power law with a gamma of 2,01. Although the display has significant white boosting, it is not reflected in the colour saturation gamma value, and the lack of constancy indicates EOTF clipping. Figure 13 (dashed line) shows an example of a tone additivity for another non-additive display which does not exhibit EOTF clipping [18] and for which the R, G, B, C, M, Y, and grey gammas are 1,99, 2,05, 2,01, 2,04, 1,69, 2,01, and 2,08, respectively. The ratio of the grey gamma (2,08) and the average colour saturation gamma (2,02) does not reflect the amount of white boosting.

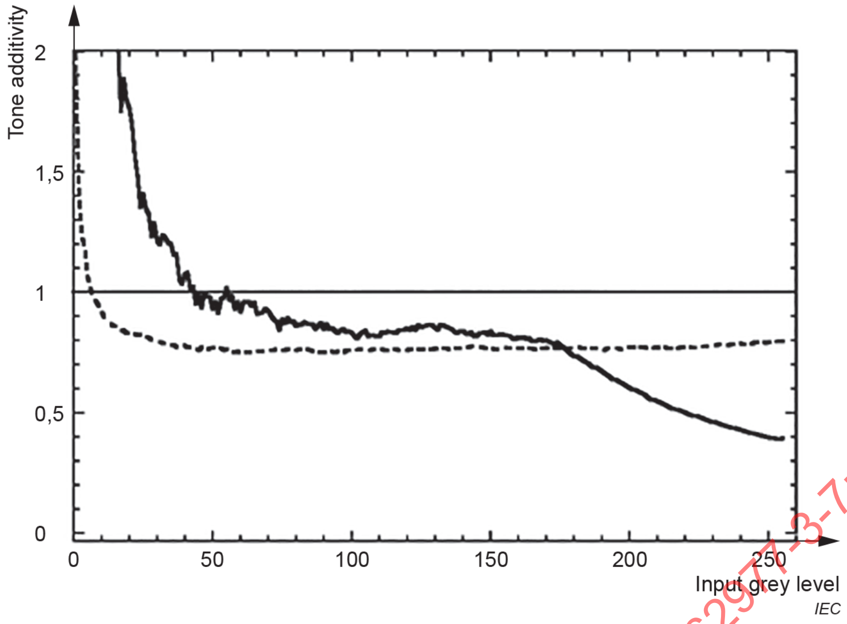


Figure 13 – Examples of tone additivity functions for non-additive displays with (solid line) and without (dashed line) tone clipping

6.4 Functional tone quantization

6.4.1 Measuring method

Although the number of quantization levels (bit depth) is specified in the signalling standard, the display does not necessarily render all these levels in perceptually distinguishable steps. The tone resolution evaluates the effective bit depth to verify how many different levels are actually rendered. Note, however, that it is not a proxy for the number of discernible colours, since it cannot simply be calculated from the product of the RGB tone resolutions. Neither is it a proxy for the perceptual tone resolution, which requires analysis in terms of JND.

Prior to the measurement, the contrast and brightness controls, if any, shall be set to their default values. Any display mode can be selected, provided that the same mode is used for all other measurements. The selected mode shall be noted in the test report. The measurement shall be done as follows:

a) The pattern in Figure 9 with grey patches (plus RGB in Figure 7 if the display is not additive) in the centre shall be used and, if there is image sticking, a black frame may be inserted between the measurements of each level.

b) The input signal bit depth shall be the same as the one specified by the display manufacturer, and the input shall range from 0 to the maximum code value at a step of one.

c) Measure the luminance of the screen centre perpendicularly to the display surface.

d) Measure in the order from low to high input value by one code value step. Grey tone is mandatory, and RGB tones are optional for additive displays.

e) Count the number of different levels according to Formula (13) and calculate the effective display bit depth using Formula (13).

f) Report ΔL_{th} and the associated effective display bit depth. If necessary, perform the measurement at each viewing direction.

Directional display bit depth measurement is recommended when the directional display EOTF is different from the EOTF in the normal direction.

6.4.2 Evaluation of functional tone quantization

To calculate the number of levels for all input codes for a given threshold luminance difference, the luminance difference between two neighbouring input code values is compared. If the luminance difference between subsequent inputs ($L_{i+1} - L_i$) is equal to or greater than a threshold of the ideal luminance difference ($L_{i+1,\text{ref}} - L_{i,\text{ref}}$), the two levels are recognized as optically different from each other. The adopted threshold ΔL_{th} for the level difference shall be reported. The number of different luminance levels is then calculated as follows:

$$N_{\text{EOTF}} = \text{Count of}\left(\frac{L_{i+1} - L_i}{L_{i+1,\text{ref}} - L_{i,\text{ref}}} \geq \Delta L_{\text{th}}\right) \tag{13}$$

where

ΔL_{th} is the adopted luminance difference threshold;

N_{EOTF} is the effective number of different luminance levels;

i is 0, 1, 2, 3,…(2^n – 2) , and n is the number of input bits.

NOTE The 10 % threshold is an example based on the luminance transition of level to level where 10 % and 90 % of the luminance variation are treated as criteria to distinguish from the base and the target level, respectively (refer to section 10.2 in [1]).

In this measurement, all pixels of the window pattern except black input shall remain turned on with equal or increasing luminous intensity as the input level increases. Figure 14 shows the minimum colour difference (ΔL) of two consecutive levels.

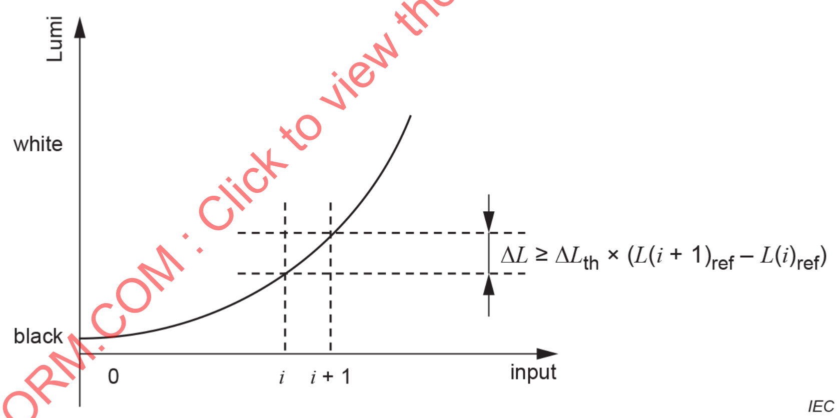


Figure 14 – Minimum luminance difference between neighbouring inputs

Based on the number of different luminance levels, the display bit depth is calculated as follows:

$$b_{\text{EOTF}} = \log_2\left(N_{\text{EOTF}} + 1\right) \tag{14}$$

where

b_{EOTF} is the effective display bit depth in number of bits.

Table 9 and Figure 15 show an example of a tone resolution evaluation in the case of 8-bit inputs. Since the number of distinguishable levels is 249, the effective display bit depth shall be 7,97 bits (= $\log_2$ (249 + 1)).

Table 9 – Example of bit depth evaluation

Input (8 bits)	Measured lumi. (normalized)	Example ref. level (γ = 2,2 case)	ΔL ratio	ΔL check in case of ΔL_{th} = 0,1
0	0,000 0	0,000 0		
1	0,000 0	0,000 0	0,00	NG
2	0,000 0	0,000 0	0,00	NG
3	0,002 1	0,000 1	62,14	-
4	0,006 3	0,000 1	83,07	-
5	0,006 6	0,000 2	4,92	-
6	0,006 9	0,000 3	3,87	-
7	0,006 9	0,000 4	0,00	NG
8	0,007 3	0,000 5	2,66	-
9	0,007 3	0,000 6	0,00	NG
10	0,007 6	0,000 8	2,01	-
11	0,007 9	0,001 0	1,78	-
12	0,008 3	0,001 2	1,60	-
13	0,008 6	0,001 4	1,44	-
14	0,008 6	0,001 7	0,00	NG
15	0,008 9	0,002 0	1,21	-
16	0,009 3	0,002 3	1,12	-
17	0,009 6	0,002 6	1,03	-
18	0,009 9	0,002 9	0,96	-
19	0,010 3	0,003 3	0,90	-
20	0,010 3	0,003 7	0,000	NG
21	0,010 6	0,004 1	0,80	-
22	0,011 3	0,004 6	1,51	-
23	0,011 6	0,005 0	0,71	-
24	0,011 9	0,005 5	0,68	-
25	0,012 3	0,006 0	0,64	-
26	0,012 9	0,006 6	1,23	-
27	0,013 3	0,007 2	0,59	-
28	0,013 6	0,007 8	0,56	-
29	0,013 9	0,008 4	0,54	-
30	0,014 6	0,009 0	1,03	-
31	0,014 9	0,009 7	0,49	-
32	0,015 3	0,010 4	0,48	-
33	0,015 9	0,011 1	0,92	-
34	0,016 6	0,011 9	0,88	-
35	0,017 0	0,012 7	0,43	-
36	0,017 3	0,013 5	0,41	-
37	0,018 0	0,014 3	0,80	-
38	0,019 0	0,015 2	1,16	-
39	0,019 3	0,016 1	0,37	-
40	0,019 6	0,017 0	0,36	-

Input (8 bits)	Measured lumi. (normalized)	Example ref. level (γ = 2,2 case)	ΔL ratio	ΔL check in case of ΔL_{th} = 0,1
41	0,020 0	0,017 9	0,35	-
42	0,021 0	0,018 9	1,03	-
43	0,021 6	0,019 9	0,66	-
44	0,022 0	0,021 0	0,32	-
45	0,022 6	0,022 0	0,63	-
46	0,023 6	0,023 1	0,92	-
47	0,024 3	0,024 2	0,57	-
48	0,025 6	0,025 4	1,16	-
49	0,027 4	0,026 5	1,49	-
50	0,028 7	0,027 8	1,08	-
. . .	. . .	. . .	. . .	. . .
255	1	1	1,12	-
Number of different levels				249
NOTE The result of the ΔL ratio is slightly different due to the limited significant figures.				

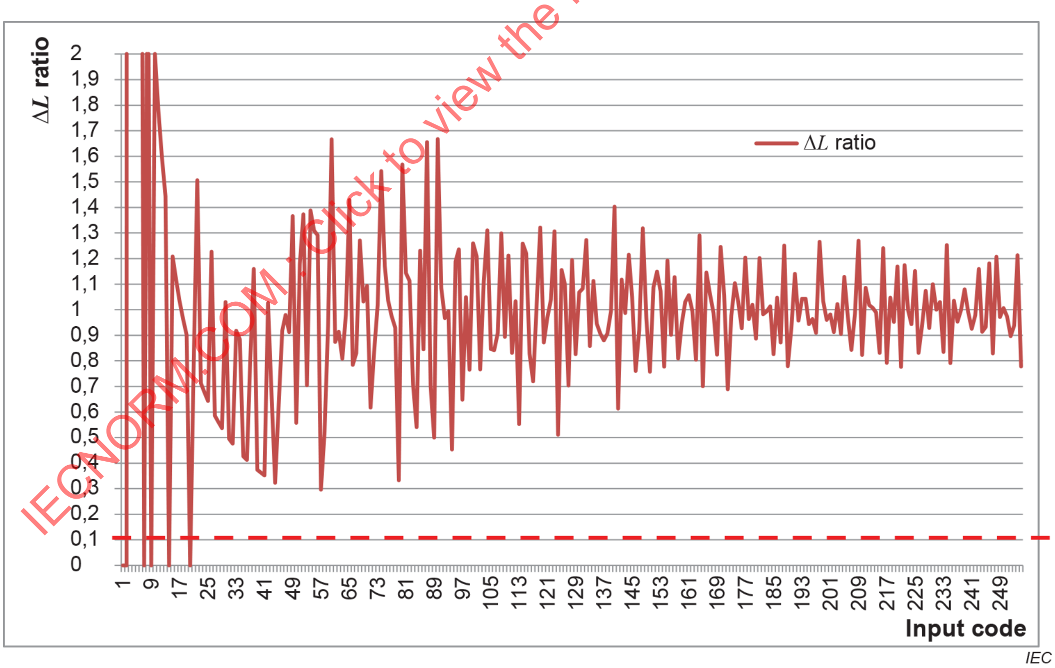


Figure 15 – Graphic result for the bit depth evaluation in Table 9

7 Reporting

7.1 Required reporting

The following information shall be reported:

a) date and time of the measurement

b) video signal generator specification
   - number of bits and input code value range
   - input pattern and signal interface format, etc
   - box size of the input pattern and APL
c) identification of the display DUT
   - product name, device name, type and lot number
   - date of production
   - company name of production
d) specification of the display DUT
   - screen size and input pixel count ($H \times V$)
   - input signal type
   - supported signal bit depth
e) selected operational mode and white point if different from the factory-set mode
f) measurement pattern used for each items or measured data from 602-point measurement in the case that the 602-point data is available
g) darkroom condition
h) LMD type for all measurements including viewing directional measurement
i) input data for colour reference pattern
j) measurement results according to 7.2

7.2 Measurement results

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

a) EOTF and display gamma
   - EOTFs: tabulated and plotted EOTF for grey and colour tone at the normal direction and viewing direction
   - gamma: average gamma or log-log gamma in the case that the EOTF obeys a power law
   - standard deviation and gamma accuracy
   - grey scale tracking accuracy: average, minimum, and maximum colour difference ΔE_{00_i}
   - directional gamma distortion in the case that the EOTFs obey a power law
b) colour saturation tone function
   - colour saturation tone curves: tabulated and plotted for each colour saturation tone
   - colour saturation tone accuracy
c) functional tone quantization
   - display bit depth for grey at the normal direction (for both an additive and a non-additive DUT)
   - display bit depth for RGB at the normal direction (for only a non-additive DUT)
d) tone additivity function: tabulated and plotted