International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R BT.2100-2

(07/2018)

Image parameter values for high dynamic range television for use in production and international programme exchange

BT Series
Broadcasting service
(television)

International
Telecommunication
Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R BT.2100-2*

Image parameter values for high dynamic range television for use in production and international programme exchange[1]

Question ITU-R 142-2/6

(2016-2017-2018)

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Scope

High Dynamic Range Television (HDR-TV) provides viewers with an enhanced visual experience by providing images that have been produced to look correct on brighter displays, that provide much brighter highlights, and that provide improved detail in dark areas. This Recommendation specifies HDR-TV image parameters for use in production and international programme exchange using the Perceptual Quantization (PQ) and Hybrid Log-Gamma (HLG) methods.

Keywords

High dynamic range, HDR, television, HDR-TV, image system parameters, television production, international programme exchange, wide colour gamut, perceptual quantization, PQ, hybrid log-gamma, HLG

The ITU Radiocommunication Assembly,

considering

a) that digital television image formats for HDTV and UHDTV have been specified by the ITU-R in Recommendations ITU-R BT.709 and ITU-R BT.2020;

b) that these television image formats have been limited in the image dynamic range they can provide due to their reliance on legacy cathode ray tube (CRT) characteristics that limit image brightness and detail in dark areas;

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* Radiocommunication Study Group 6 made editorial amendments to this Recommendation in the years 2018, 2019 and 2020 in accordance with Resolution ITU-R 1.

[1] Revisions to parameter values within this document should be compared to those in the previously published version of this Recommendation.

c) that modern displays are capable of reproducing images at a higher luminance, greater contrast ratio and wider colour gamut than is conventionally employed in programme production;

d) that viewers expect future television viewing to provide improved characteristics compared with the current HDTV and UHDTV in terms of a more realistic sensation, greater transparency to the real world and more accurate visual information;

e) that high dynamic range television (HDR-TV) has been shown to increase viewer enjoyment of television pictures;

f) that HDR-TV provides a "step-change" improvement in viewer experience by means of substantially increased brightness and detail in highlights and diffuse reflecting objects, while providing greater detail in dark areas;

g) that the combination of extended dynamic range and extended colour gamut give HDR-TV a substantially larger colour volume;

h) that the HDR-TV image formats should have, where appropriate, a degree of compatibility with existing workflows and infrastructure;

i) that a reference viewing environment including display parameters should be defined for HDR-TV image formats,

further considering

that due to rapid developments in HDR technology the ITU may wish to consider early updates and improvements to this Recommendation,

recognizing

that Report ITU-R BT.2390 contains much information on two methods to achieve HDR-TV,

recommends

that for programme production and international exchange of HDR-TV, the perceptual quantization (PQ) or Hybrid Log-Gamma (HLG) specifications described in this Recommendation should be used.

NOTE – The PQ specification achieves a very wide range of brightness levels for a given bit depth using a non-linear transfer function that is finely tuned to match the human visual system. The HLG specification offers a degree of compatibility with legacy displays by more closely matching the previously established television transfer curves. Report ITU-R BT.2390 provides additional information on PQ and HLG, conversion between them, and compatibility with previous systems.

TABLE 1

Image spatial and temporal characteristics

Parameter	Values
Image Container [1a] Shape	16:9
Container Pixel count [1b] Horizontal × Vertical	7 680 × 4 320 3 840 × 2 160 1 920 × 1 080
Sampling lattice	Orthogonal
Pixel aspect ratio	1:1 (square pixels)
Pixel addressing	Pixel ordering in each row is from left to right, and rows are ordered from top to bottom.
Frame frequency (Hz)	120, 120/1.001,100, 60, 60/1.001, 50, 30, 30/1.001, 25, 24, 24/1.001
Image Format	Progressive

Note 1a – Container is used to define the horizontal and vertical constraints of the image format.

Note 1b – Productions should use the highest resolution image format that is practical. It is recognized that in many cases high resolution productions will be down-sampled to lower resolution formats for distribution. It is known that producing in a higher resolution format, and then electronically down-sampling for distribution, yields superior quality than producing at the resolution used for distribution.

TABLE 2

System colorimetry

Parameter		Values		
		Optical spectrum (informative)	Chromaticity coordinates (CIE, 1931)	
			x	***y***
Primary colours	Red primary (R)	monochromatic 630 nm	0.708	0.292
	Green primary (G)	monochromatic 532 nm	0.170	0.797
	Blue primary (B)	monochromatic 467 nm	0.131	0.046
Reference white		D65 per ISO 11664-2:2007	0.3127	0.3290
Colour Matching Functions		CIE 1931		

Table 3 specifies parameters to establish a reference viewing environment for critical viewing of HDR programme material or completed programmes that can provide repeatable results from one facility to another when viewing the same material. Viewing facilities can and will continue to be established in many ways by entities involved in editing, colour correction, screening and the like, and the specifications in this Table are not intended to suggest a need for absolute uniformity in such facilities.

TABLE 3

Reference viewing environment for critical viewing of HDR programme material

Parameter	Values
Surround and periphery [3a]	Neutral grey at D65
Luminance of surround	5 cd/m^2
Luminance of periphery	≤ 5 cd/m^2
Ambient lighting	Avoid light falling on the screen
Viewing distance [3b]	For 1 920 × 1 080 format: 3.2 picture heights For 3 840 × 2 160 format: 1.6 to 3.2 picture heights For 7 680 × 4 320 format: 0.8 to 3.2 picture heights
Peak luminance of display [3c]	≥ 1 000 cd/m^2
Minimum luminance of display (black level) [3d]	≤ 0.005 cd/m^2

Note 3a – “Surround” is the area surrounding a display that can affect the adaptation of the eye, typically the wall or curtain behind the display; “periphery” is the remaining environment outside of the surround.

Note 3b – When picture evaluation involves resolution, the lower value of viewing distance should be used. When resolution is not being evaluated, any viewing distance in the indicated range may be used.

Note 3c – This is not to imply this level of luminance must be achieved for full screen white, rather for small area highlights.

Note 3d – For PQ in a non-reference viewing environment, or for HLG (in any viewing environment), the black level should be adjusted using the PLUGE test signal and procedure specified in Recommendation ITU-R BT.814.

Tables 4 and 5 describe transfer functions for the PQ and HLG formats, respectively. High dynamic range television production and display should make consistent use of the transfer functions of one system or the other and not intermix them. Informative Annex 1 illustrates the meaning of the various transfer functions and where they are used in the signal chain. Informative Annex 2 provides information on alternate equations that could facilitate implementation of these transfer functions.

TABLE 4

PQ system reference non-linear transfer functions

Parameter	Values
Input signal to PQ electro-optical transfer function (EOTF)	Non-linear PQ encoded value. The EOTF maps the non-linear PQ signal into display light.
Reference PQ EOTF [4a]	$F_D = \mathrm{EOTF}[E'] = 10000\,Y$ $Y = \left(\dfrac{\max\left[\left(E'^{1/m_2} - c_1\right), 0\right]}{c_2 - c_3 E'^{1/m_2}} \right)^{1/m_1}$ where: E' denotes a non-linear colour value $\{R', G', B'\}$ or $\{L', M', S'\}$ in PQ space in the range [0:1] F_D is the luminance of a displayed linear component $\{R_D, G_D, B_D\}$ or Y_D or I_D, in cd/m^2. [4b] Y denotes the normalized linear colour value, in the range [0:1] $m_1 = 2610/16384 = 0.1593017578125$ $m_2 = 2523/4096 \times 128 = 78.84375$ $c_1 = 3424/4096 = 0.8359375 = c_3 - c_2 + 1$ $c_2 = 2413/4096 \times 32 = 18.8515625$ $c_3 = 2392/4096 \times 32 = 18.6875$
Input signal to PQ opto-optical transfer function (OOTF)	Scene linear light. The OOTF maps relative scene linear light to display linear light.
Reference PQ OOTF	$F_D = \mathrm{OOTF}[E] = \mathrm{G}_{1886}\,[\mathrm{G}_{709}[E]]$ where: $E = \{R_S, G_S, B_S;\ Y_S;$ or $I_S\}$ is the signal determined by scene light and scaled by camera exposure The values $E, R_S, G_S, B_S, Y_S, I_S$ are in the range [0:1] [4c] E' is a non-linear representation of E F_D is the luminance of a displayed linear component ($R_D, G_D, B_D;\ Y_D;$ or I_D) $F_D = \mathrm{G}_{1886}\,[\mathrm{G}_{709}[E]] = \mathrm{G}_{1886}\,E'$ $E' = \mathrm{G}_{709}[E] = 1.099\,(59.5208\,E)^{0.45} - 0.099$ for $1 > E > 0.0003024$ $= 267.84\,E$ for $0.0003024 \geq E \geq 0$ $F_D = \mathrm{G}_{1886}[E'] = 100\,E'^{2.4}$
Input signal to PQ opto-electronic transfer function (OETF)	Scene linear light. The OETF maps relative scene linear light into the non-linear PQ signal value.

TABLE 4 (*end*)

Parameter	**Values**
Reference PQ OETF Use of this OETF will yield the reference OOTF when displayed on a reference monitor employing the reference EOTF.	$E' = \mathrm{OETF}[E] = \mathrm{EOTF}^{-1}[\mathrm{OOTF}[E]] = \mathrm{EOTF}^{-1}[F_D]$ where $\mathrm{EOTF}^{-1}[F_D] = \left(\frac{c_1 + c_2 Y^{m_1}}{1 + c_3 Y^{m_1}}\right)^{m_2}$ $Y = F_D/10000$ E' is the resulting non-linear signal (R', G', B') in the range [0:1] F_D, E, are as specified in the opto-optical transfer function m_1, m_2, c_1, c_2, c_3 are as specified in the electro-optical transfer function.

Note 4a – This same non-linearity (and its inverse) should be used when it is necessary to convert between the non-linear representation and the linear representations.

Note 4b **–** In this Recommendation, when referring to the luminance of a single colour component (R_D, G_D, B_D), it means the luminance of an equivalent achromatic signal with all three colour components having that same value.

Note 4c – The mapping of the camera sensor signal output to E may be chosen to achieve the desired brightness of the scene.

TABLE 5

Hybrid Log-Gamma (HLG) system reference non-linear transfer functions

Parameter	**Values**
Input signal to HLG OETF	Scene linear light. The OETF maps relative scene linear light into the non-linear signal value.
HLG Reference OETF [5a]	$E' = \mathrm{OETF}[E] = \begin{cases} \sqrt{3E} & 0 \le E \le \frac{1}{12} \\ a \cdot \ln(12E - b) + c & \frac{1}{12} < E \le 1 \end{cases}$ where: E is a signal for each colour component $\{R_S, G_S, B_S\}$ proportional to scene linear light normalized to the range [0:1]. [5b] E' is the resulting non-linear signal $\{R', G', B'\}$ in the range [0:1]. $a = 0.17883277$, $b = 1 - 4a$, $c = 0.5 - a \cdot \ln(4a)$ [5c]
HLG Input signal to OOTF	Scene linear light. The OOTF maps relative scene linear light to display linear light.

TABLE 5 (*end*)

Parameter	**Values**
HLG Reference OOTF [5i]	$F_D = \mathrm{OOTF}[E] = \alpha Y_S^{\gamma-1} E$ $R_D = \alpha Y_S^{\gamma-1} R_S$ $G_D = \alpha Y_S^{\gamma-1} G_S$ $B_D = \alpha Y_S^{\gamma-1} B_S$ $Y_s = 0.2627 R_S + 0.6780 G_S + 0.0593 B_S$ where: F_D is the luminance of a displayed linear component $\{R_D, G_D$, or $B_D\}$, in cd/m^2. [5d] E is a signal for each colour component $\{R_s, G_s, B_s\}$ proportional to scene linear light normalized to the range [0:1]. Y_S is the normalized linear scene luminance. α is the variable for user gain in cd/m^2. It represents L_W, the nominal peak luminance of a display for achromatic pixels. γ is the system gamma. γ = 1.2 at the nominal display peak luminance of 1 000 cd/m^2. [5e, 5f, 5g]
Input signal to HLG EOTF	Non-linear HLG encoded value. The EOTF maps the non-linear HLG signal into display light.
HLG Reference EOTF	$F_D = \mathrm{EOTF}\left[\max\left(0, (1-\beta)E' + \beta\right)\right]$ $= \mathrm{OOTF}\left[\mathrm{OETF}^{-1}\left[\max\left(0, (1-\beta)E' + \beta\right)\right]\right]$ where: F_D is the luminance of a displayed linear component $\{R_D, G_D$, *or* $B_D\}$, in cd/m^2. E' is the non-linear signal $\{R', G', B'\}$ as defined for the HLG Reference OETF. [5h] β is the variable for user black level lift. OOTF[ ] is as defined for the HLG Reference OOTF. $\mathrm{OETF}^{-1}[x] = \begin{cases} x^2/3 & 0 \le x \le 1/2 \\ \{\exp((x-c)/a) + b\}/12 & 1/2 < x \le 1 \end{cases}$ The values of parameters a, b, and c are as defined for the HLG Reference OETF. and: $\beta = \sqrt{3 (L_B / L_W)^{1/\gamma}}$ L_W is nominal peak luminance of the display in cd/m^2 for achromatic pixels. L_B is the display luminance for black in cd/m^2.

Notes to Table 5

Note 5a – The inverse of this non-linearity should be used when it is necessary to convert between the non-linear representation and the linear representation of scene light.

Note 5b – The mapping of the camera sensor signal output to E may be chosen to achieve the desired brightness of the scene.

Note 5c – The values of b and c are calculated to $b = 0.28466892$, $c = 0.55991073$.

Note 5d – In this Recommendation, when referring to the luminance of a single colour component (R_D, G_D, B_D), it means the luminance of an equivalent achromatic signal with all three colour components having that same value.

Note 5e – This EOTF applies gamma to the luminance component of the signal, whereas some legacy displays may apply gamma separately to colour components. Such legacy displays approximate this reference OOTF.

Note 5f – For displays with nominal peak luminance (L_W) greater than 1 000 cd/m^2, or where the effective nominal peak luminance is reduced through the use of a contrast control, the system gamma value should be adjusted according to the formula below[2], and may be rounded to three significant digits:

$$\gamma = 1.2 + 0.42\,\mathrm{Log}_{10}\left(L_W / 1000\right)$$

Note 5g – The system gamma value may be decreased for brighter background and surround conditions.

Note 5h – During production, signal values are expected to exceed the range E' = [0.0 : 1.0]. This provides processing headroom and avoids signal degradation during cascaded processing. Such values of E', below 0.0 or exceeding 1.0, should not be clipped during production and exchange. Values below 0.0 should not be clipped in reference displays (even though they represent “negative” light) to allow the black level of the signal (L_B) to be properly set using test signals known as “PLUGE”.

Note 5i – The inverse of HLG OOTF is derived as follows:

$$R_S = \left(\frac{Y_D}{\alpha}\right)^{(1-\gamma)/\gamma} \frac{R_D}{\alpha}$$

$$G_S = \left(\frac{Y_D}{\alpha}\right)^{(1-\gamma)/\gamma} \frac{G_D}{\alpha}$$

$$B_S = \left(\frac{Y_D}{\alpha}\right)^{(1-\gamma)/\gamma} \frac{B_D}{\alpha}$$

$$Y_D = 0.2627 R_D + 0.6780 G_D + 0.0593 B_D$$

For processing purposes, when the actual display is not known, α may be set to 1.0 cd/m^2.

Tables 6 and 7 describe different luminance and colour difference signal representations, suitable for colour sub-sampling, and/or source coding. The Non-Constant Luminance (NCL) format is in widespread use and is considered the default. The Constant Intensity (CI) format is newly introduced in this Recommendation and should not be used for programme exchange unless all parties agree.

TABLE 6

Non-Constant Luminance $Y'C'_BC'_R$ signal format [6a]

Parameter	**Values PQ**	**Values HLG**
Derivation of R', G', B'	$\{R', G', B'\} = \mathrm{EOTF}^{-1}(F_D)$ where $F_D = \{R_D, G_D, B_D\}$	$\{R', G', B'\} = \mathrm{OETF}(E)$ where $E = \{R_S, G_S, B_S\}$
Derivation of Y'	$Y' = 0.2627R' + 0.6780G' + 0.0593B'$	
Derivation of colour difference signals	$C'_B = \frac{B' - Y'}{1.8814}$ $C'_R = \frac{R' - Y'}{1.4746}$	

Note 6a – For consistency with prior use of terms, Y', C'_B and C'_R employ prime symbols indicating they have come from non-linear Y, B and R.

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[2] For applications in which L_W is outside the range 400 cd/m^2 to 2 000 cd/m^2 the following formula may be used: $\gamma = 1.2 * \kappa^{\mathrm{Log}_2(L_W/1000)}$ where κ = 1.111.

TABLE 7

Constant Intensity IC_TC_P signal format [7a, 7b]

Parameter	Values PQ	Values HLG
L, M, S Colour Space	$L = (1688R + 2146G + 262B)/4096$ $M = (683R + 2951G + 462B)/4096$ $S = (99R + 309G + 3688B)/4096$	
Derivation of L', M', S' [7c]	$\{L', M', S'\}=\text{EOTF}^{-1}(F_D)$ where $F_D = \{L_D, M_D, S_D\}$	$\{L', M', S'\}=\text{OETF}(E)$ where $E = \{L_S, M_S, S_S\}$
Derivation of I	$I = 0.5L' + 0.5M'$	
Derivation of colour difference signals	$C_T = (6610L' - 13613M' + 7003S')/4096$ $C_P = (17933L' - 17390M' - 543S')/4096$	$C_T = (3625L' - 7465M' + 3840S')/4096$ $C_P = (9500L' - 9212M' - 288S')/4096$

Note 7a – The newly introduced I, C_T and C_P symbols do not employ the prime symbols to simplify the notation.

Note 7b –Colours should be constrained to be within the triangle defined by the RGB colour primaries in Table 2.

Note 7c – The subscripts D and S refer to display light and scene light, respectively.

TABLE 8

Colour sub-sampling

<table>
<tr><th>Parameters</th><th colspan="3">Values</th></tr>
<tr><td>Coded signal</td><td colspan="3">R', G', B' or Y', C'_B, $C'_{R,}$, or I, $C_{T,}$ C_P</td></tr>
<tr><td>Sampling lattice
– R', G', B', Y', I</td><td colspan="3">Orthogonal, line and picture repetitive co-sited</td></tr>
<tr><td rowspan="3">Sampling lattice
– C'_B, C'_R, C_T, C_P</td><td colspan="3">Orthogonal, line and picture repetitive co-sited with each other.
The first (top-left) sample is co-sited with the first Y' or I samples.</td></tr>
<tr><td>4:4:4 system</td><td>4:2:2 system</td><td>4:2:0 system</td></tr>
<tr><td>Each has the same number of horizontal samples as the Y' or I component.</td><td>Horizontally subsampled by a factor of two with respect to the Y' or I component.</td><td>Horizontally and vertically subsampled by a factor of two with respect to the Y' or I component.</td></tr>
</table>

Table 9 describes two different signal representations, “narrow” and “full”. The narrow range representation is in widespread use and is considered the default. The full range representation is newly introduced in this Recommendation and should not be used for programme exchange unless all parties agree.

TABLE 9

Digital 10- and 12-bit integer representation

Parameters	**Values**			
Coded signal	R', G', B' or Y', C'_B, C'_R, or I, C_T, C_P			
Coding format	n = 10, 12 bits per component			
Quantization of R', G', B', Y', I (resulting values that exceed the video data range should be clipped to the video data range)	Narrow range		Full range	
	$D = \text{Round}\ [(219 \times E' + 16) \times 2^{n-8}]$		$D = \text{Round}\ [(2^n\text{-}1) \times E']$	
Quantization of C'_B, C'_R, C_T, C_P (resulting values that exceed the video data range should be clipped to the video data range)	$D = \text{Round}\ [(224 \times E' + 128) \times 2^{n-8}]$		$D = \text{Round}\ [(2^n\text{-}1) \times E' + 2^{n\text{-}1}]$	
Quantization levels	10-bit coding	12-bit coding	10-bit coding	12-bit coding
Black $(R' = G' = B' = Y' = I = 0)$ DR', DG', DB', DY', DI	64	256	0	0
Nominal Peak $(R' = G' = B' = Y' = I = 1)$ DR', DG', DB', DY', DI	940	3760	1023	4095
Achromatic $(C'_B = C'_R = 0)$ DC'_B, DC'_R, DC_T, DC_P	512	2048	512	2048
Nominal Peak $(C'_B = C'_R = +0.5)$ DC'_B, DC'_R, DC_T, DC_P	960	3840	1023	4095
Nominal Peak $(C'_B = C'_R = \text{-}0.5)$ DC'_B, DC'_R, DC_T, DC_P	64	256	1	1
Video data range [9a, 9b]	4 through 1019	16 through 4079	0 through 1023	0 through 4095

Where:

Round(x) = Sign(x) * Floor(| x | + 0.5)

Floor(x)the largest integer less than or equal to x

$$\text{Sign(x)} = \begin{cases} 1 & ; \quad x > 0 \\ 0 & ; \quad x = 0 \\ -1 & ; \quad x < 0 \end{cases}$$

Note 9a – Narrow range signals may extend below black (sub-blacks) and exceed the nominal peak values (super-whites), but should not exceed the video data range.

Note 9b – Some digital image interfaces reserve digital values, e.g. for timing information, such that the permitted video range of these interfaces is narrower than the video range of the full-range signal. The mapping from full-range images to these interfaces is application-specific.

Table 10 introduces a 16-bit floating point signal representation. Currently, real-time interfaces do not exist for this format. It is expected that this format would initially see usage in file-based workflows and programme exchange.

TABLE 10

Floating Point (FP) signal representation

Parameter	Values
Signal representation	Linear R, G, B.
Signal encoding	16-bit floating point per IEEE standard 754-2008.
Normalization for display-referred signals	$R = G = B = 1.0$ represents 1.0 cd/m^2 on the reference display.
Normalization for scene-referred signals	$R = G = B = 1.0$ represents the maximum diffuse white level.

Annex 1
(informative)

The relationship between the OETF, the EOTF and the OOTF

This Recommendation makes extensive use of the following terms:

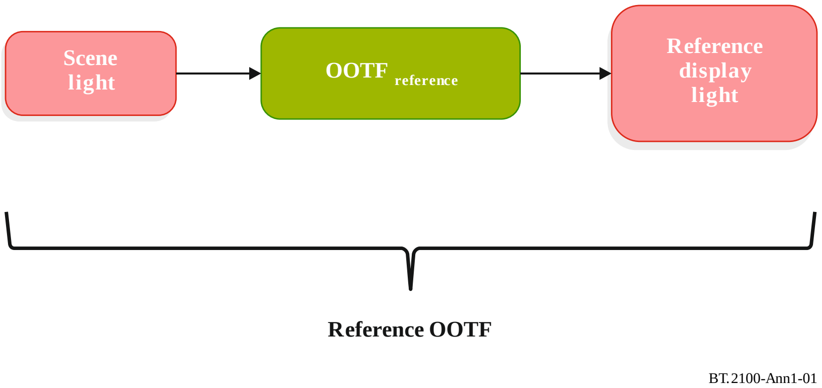
OETF: the opto-electronic transfer function, which converts linear scene light into the video signal, typically within a camera.

EOTF: electro-optical transfer function, which converts the video signal into the linear light output of the display.

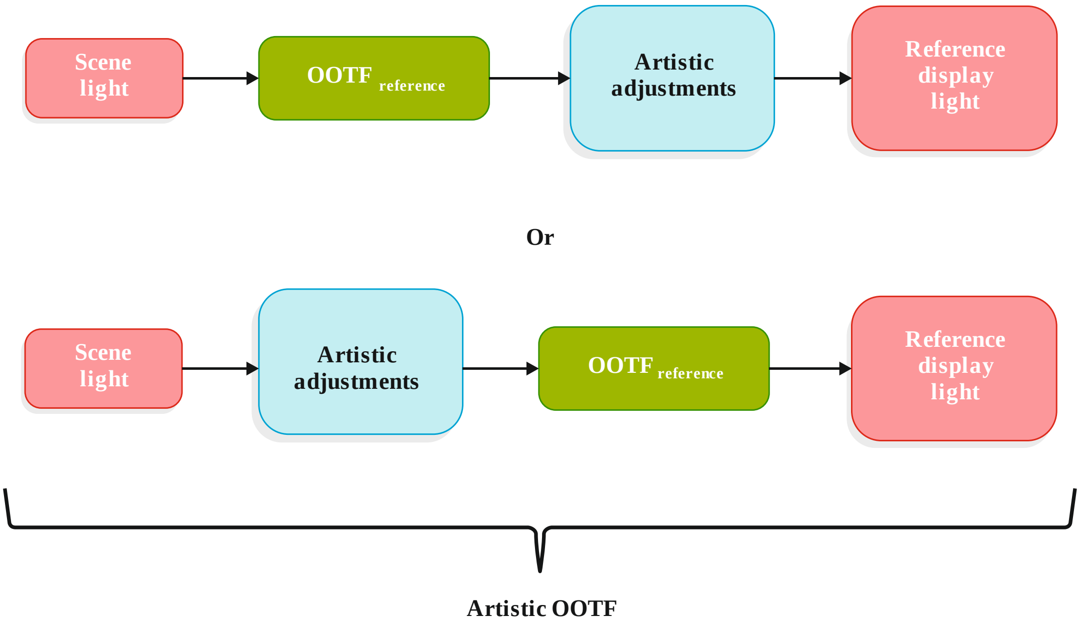
OOTF: opto-optical transfer function, which has the role of applying the "rendering intent".

These functions are related, so only two of the three are independent. Given any two of them the third one may be calculated. This section explains how they arise in television systems and how they are related.

In television systems the displayed light is not linearly related to the light captured by the camera. Instead an overall non-linearity is applied, the OOTF. The "reference" OOTF compensates for difference in tonal perception between the environment of the camera and that of the display. Specification and use of a "reference OOTF" allows consistent end-to-end image reproduction, which is important in TV production.



Artistic adjustment may be made to enhance the picture. These alter the OOTF, which may then be called the "artistic OOTF". Artistic adjustment may be applied either before or after the reference OOTF.



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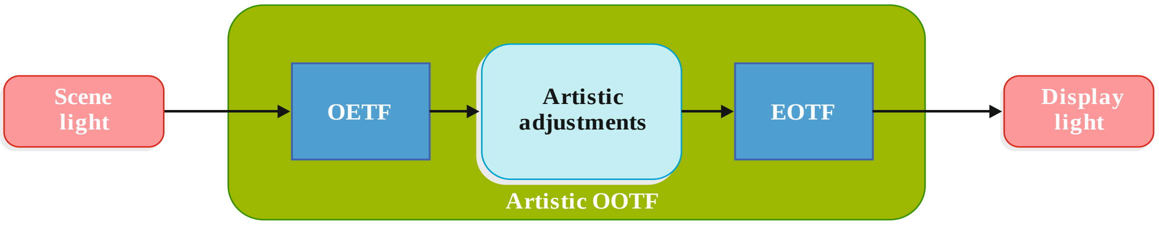
In general the OOTF is a concatenation of the OETF, artistic adjustments, and the EOTF.



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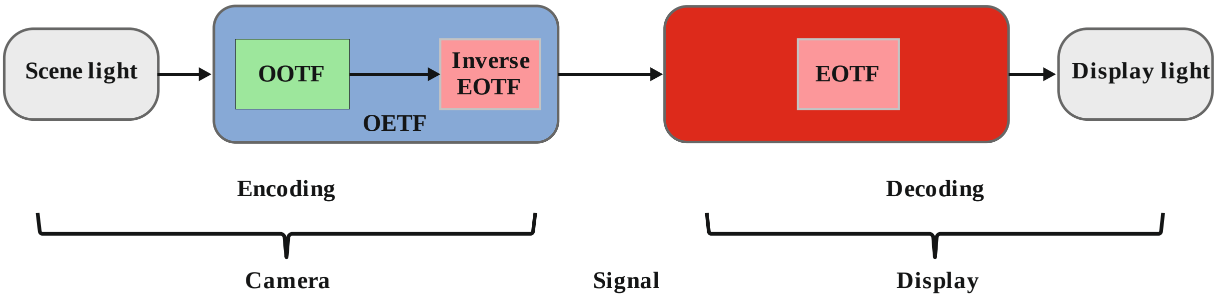
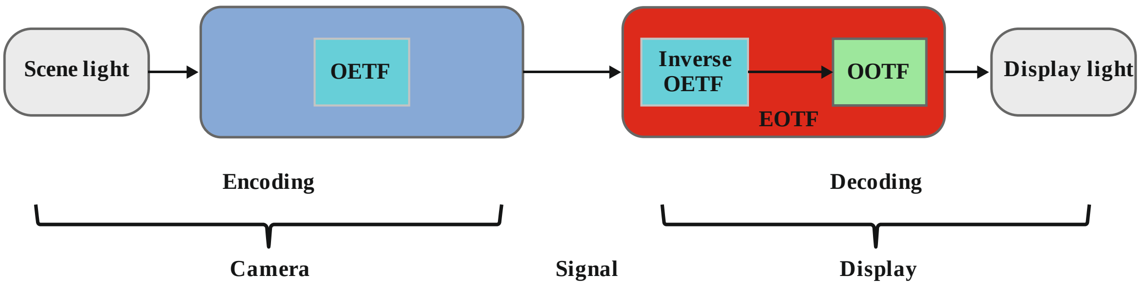
The PQ system was designed with the model shown below, where the OOTF is considered to be in the camera (or imposed in the production process).



BT.2100-Ann1-04

The HLG system was designed with the model shown below, where the OOTF is considered to be in the display.



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Only two of three non-linearities, the OETF, the EOTF, and the OOTF, are independent. In functional notation (where subscripts indicate the colour component):

$$\mathrm{OOTF}_R(R,G,B) = \mathrm{EOTF}_R(\mathrm{OETF}_R(R,G,B))$$
$$\mathrm{OOTF}_G(R,G,B) = \mathrm{EOTF}_G(\mathrm{OETF}_G(R,G,B))$$
$$\mathrm{OOTF}_B(R,G,B) = \mathrm{EOTF}_B(\mathrm{OETF}_B(R,G,B))$$

This is clearer if the concatenation is represented by the symbol ⊗. With this notation, the following three relationships between these three non-linearities are obtained:

$$\mathrm{OOTF} = \mathrm{OETF} \otimes \mathrm{EOTF}$$
$$\mathrm{EOTF} = \mathrm{OETF}^{-1} \otimes \mathrm{OOTF}$$
$$\mathrm{OETF} = \mathrm{OOTF} \otimes \mathrm{EOTF}^{-1}$$
$$\mathrm{OOTF}^{-1} = \mathrm{EOTF}^{-1} \otimes \mathrm{OETF}^{-1}$$
$$\mathrm{EOTF}^{-1} = \mathrm{OOTF}^{-1} \otimes \mathrm{OETF}$$
$$\mathrm{OETF}^{-1} = \mathrm{EOTF} \otimes \mathrm{OOTF}^{-1}$$

The PQ approach is defined by its EOTF. For PQ, the OETF may be derived from the OOTF using the third line of the equations above. In a complementary fashion the HLG approach is defined by its OETF. For HLG, the EOTF may be derived from the OOTF using the second line of the equations above.

Annex 2
(informative)

Parametric representation of electro-optical and opto-electronic transfer functions

This Annex in connection with appropriate parameter sets facilitates the implementation of the reference opto-electronic transfer functions (OETFs), as well as the reference electro-optical transfer functions (EOTFs) of this Recommendation.

An EOTF may be represented by equation (1):

$$L(V) = \left(\frac{c - (V - m)st}{V - m - s} \right)^{1/n} \qquad (1)$$

where:

V: nonlinear colour value

L: corresponding linear colour value.

The parameter set $\{s, t, c, n, m\}$ can be set according to a desired application.

An OETF may be represented by equation (2):

$$V(L) = \frac{sL^n + c}{L^n + st} + m \tag{2}$$

It should be noted that if the parameters s, t, c, n and m are given identical values in equations (1) and (2), then $L(V)$ and $V(L)$ are the mathematical inverse of each other.

In certain applications, it is helpful to normalize V in equations (1) and (2) according to equation (3):

$$\hat{V} = \frac{V - p}{k} + m \tag{3}$$

where:

V: non-linear colour value

$\hat{V}$: normalized non-linear colour value that replaces V in equations (1) and (2).

The parameters k and p can be set according to a desired application.

In certain applications, it is helpful to normalize L in equations (1) and (2) according to equation (4):

$$\hat{L} = \frac{L - b}{a} \tag{4}$$

where:

L: linear colour value

$\hat{L}$: normalized linear colour value that replaces L in equations (1) and (2).

The parameters a and b can be set according to a desired application.

Using these equations, an actual implementation may be created by specifying values for each of the parameters. As an example, a linear normalised signal may have to be reproduced, in which case the parameters for equation (3) are: $p = m = 0$ and $k = 1$. The parameters for equation (4) would then be: $a = 1$ and $b = 0$. A sample pair of OETF and EOTF with a system gamma of 1.0, serving as a starting point, can be implemented using equations (1) and (2), with parameters $s = 1$, $\mathrm{t} = \mathrm{m} = 0.2701$, $\mathrm{c} = -0.0729$, $\mathrm{n} = 0.4623$.