BBC | Research & Development

HLG Look-Up Table Licensing

Part of the HDR-TV series. Last updated June 2019 for LUT release v1.3.1

Introduction

To facilitate the introduction of HLG production, BBC R&D are licensing a package of look-up tables (LUTs) which implement a range of key format conversions.

The conversions are available as 33-cube 3D-LUTs, with some critical conversions also available as 65-cube LUTs. They include:

- BT.2100 PQ (1000 cd/m^2 nominal peak) to BT.2100 HLG
- BT.2100 PQ (4000 cd/m^2 nominal peak) to BT.2100 HLG
- BT.709 (SDR) to BT.2100 HLG (display-referred direct mapping maintaining SDR "look")
- BT.709 (SDR) to BT.2100 HLG (scene-referred direct mapping for matching cameras)
- BT.709 (SDR) to BT.2100 HLG (display-referred "up-mapping"/ "inverse tone mapping" to maintain SDR artistic intent)
- BT.709 (SDR) to BT.2100 HLG (scene-referred "up-mapping"/ "inverse tone mapping" for matching SDR and HDR cameras)
- BT.2100 HLG to BT.2100 PQ (1000 cd/m^2 nominal peak)
- BT.2100 HLG to BT.709 (SDR) (display-referred "down-mapping"/ "tone mapping" maintaining HDR "look")
- BT.2100 HLG to BT.709 (SDR) (scene-referred "down-mapping"/ " tone mapping" to match SDR cameras)
- S-Log3 SR-Live (BT.2020 colour) to BT.2100 HLG (scene-referred conversion to match BT.2100 HLG cameras)
- PQ P3D65 (1000 cd/m^2 nominal peak) to BT.2100 HLG
- BT.2100 HLG to PQ P3D65 (1000 cd/m^2 nominal peak)
- BT.2100 HLG to PQ (110 cd/m^2 nominal peak) X′Y′Z′ (HDR movie)
- Test LUTs to verify the correct operation of LUT hardware.

Additional conversions may be added in the future.

The scene-light LUTs will only work correctly with ITU-R BT.2100 signals. They will not colour match cameras configured for Sony's "HLG Live" variant, nor the "Traditional Colour" variant of HLG specified in ITU-R report BT.2390, described as "HLG Vivid" in Canon cameras.

As part of the package we also offer a 65-cube 3D-LUT for loading into a Dolby PRM-4200/4220 display, to add support for BT.2100 HLG.

LUT Details

The complete list of conversions is shown in Table 4 (a, b and c). New LUTs that have been added or improved as part of the version 1.3 update are highlighted in blue and bold. More details for the majority of the LUTs are given in Annex, including the expected output for values for SMPTE RP 219 BT.709 Colour Bars, ITU-R BT.2111 HDR Colour Bars or a new HDR "line-up" version of colour bars that is designed to be more robust to HDR/SDR format conversion.

Three types of LUT are included, that scale the input and output video in different ways:

- **Type I** LUTs are intended for software applications, and older LUT devices that do not operate over the full 10-bit SDI signal range;

- **Type II** LUTs are intended for full-range SDI input signals such as S-Log3 and those produced by some PQ devices;

- **Type III** LUTs are intended for LUT devices that process narrow-range video signals, but which operate over the full 10-bit signal range (0 to 1023). They will therefore pass sub-blacks[1] and super-whites[2] (required for ITU-R BT.814 HDR PLUGE and ITU-R BT.2111 HDR Colour Bars), so are most suitable for broadcast TV applications.

The three LUT types are illustrated in Figures 1 to 3:

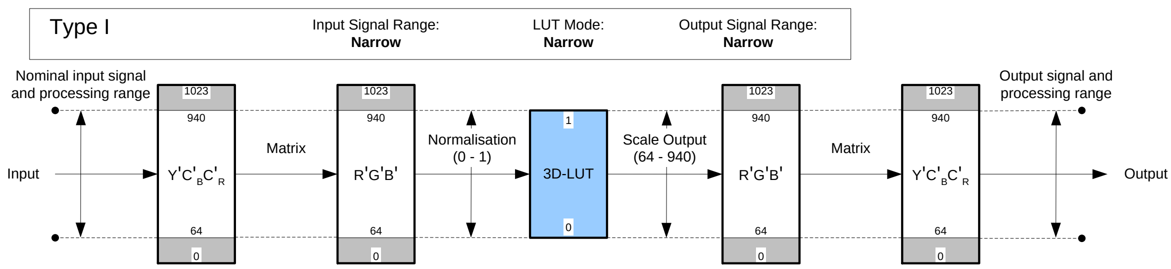

Figure 1- Type I signal scaling, primarily intended for software-based LUT applications

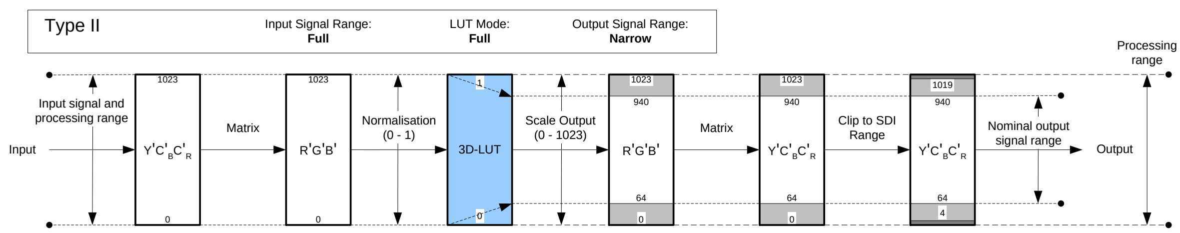

Figure 2 - Type II signal scaling, intended for full-range input signals (e.g. S-Log3)

[1] signals below 10-bit code value 64
[2] signals above 10-bit code value 940

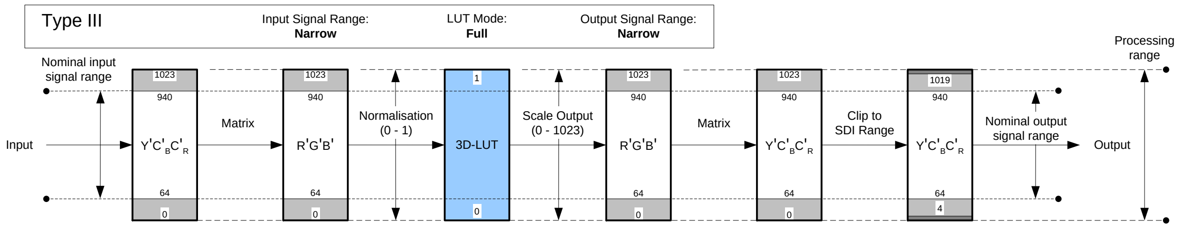

Figure 3 - Type III signal scaling, primarily intended for hardware-based LUT applications

The Type II "full-range mode" LUT is used to convert full-range PQ and S-Log3 signals to HLG. So full-range Type II versions of the PQ1000, PQ4000, S-Log3 (100%) and S-Log3 (200%) conversion LUTs are provided.

We recommended only using narrow-range signals with HLG, to improve interoperability, maintain signal fidelity and reduce the likelihood of errors in production. So even when a hardware LUT device is operated in full-range mode, the HLG output signal is always offset and scaled within the full-range "container", to lie within the usual narrow signal range of 64 to 940 (10-bits).

Scene-Light vs Display-Light Conversions

Most SDR/HDR format conversions are based on "display-light". By that we mean that the conversion calculates the light produced by the original signal on a reference display operating in the original format, and attempts to produce a similar light output on a reference display operating in the new output format. Display-light conversions are designed to preserve the artistic intent of the pictures after conversion. So display-light conversions work well for graded content. An example of a display-light conversion for BT.709 to BT.2100 HLG is shown in Figure 4 below.

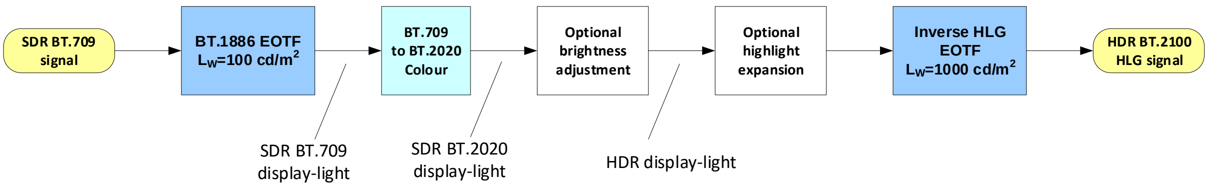

Figure 4 - SDR to HDR Display-Light Conversion

For live production, however, it is usually more important to colour match signals produced in different formats – for example a native BT.2100 HLG camera with an SDR BT.709 super slo-mo camera. However, as the native displayed "look" of the SDR BT.709, SDR BT.2020, BT.2100 HLG, BT.2100 PQ and S-Log3 (SR-Live) production formats are all different (in terms of colour and tone reproduction), colour matching of cameras will be difficult using display-light conversions. Instead, a scene-light conversion should be used.

A scene-light conversion first calculates the light falling on the camera sensor by applying an inverse OETF, then any colour space conversion and highlight expansion, and finally derives the output signal by applying the output format's OETF. As the light falling on the camera sensor is the same regardless of production format, a more exact colour and tone match is obtained than through display-light conversion. An example of a scene-light conversion for BT.709 to BT.2100 HLG is shown in Figure 5 below.

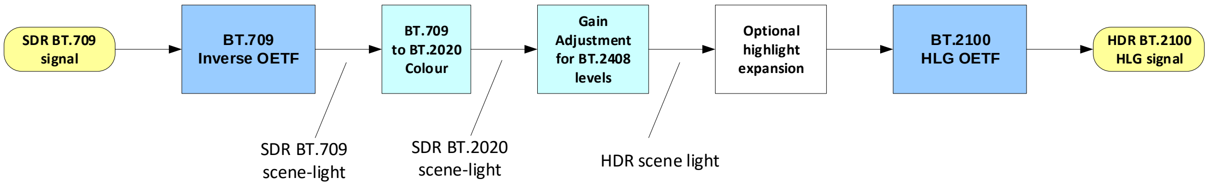

Figure 5 - Scene-light SDR to HDR conversion

Scene-light conversions are also useful for HDR to SDR conversion, where the desire is to match the "look" of a traditional SDR camera. For example, the LUT 12 (scene-light conversion from BT.2100 HLG to SDR BT.709) should be used when a BT.2100 HLG production is required to provide an SDR BT.709 output that closely resembles the "look" of a traditional SDR BT.709 camera; perhaps for intercutting with SDR BT.709 cameras covering the same event in SDR.

More details can be found in section 7.1.3 of ITU-R report BT.2408, "Guidance for Operational Practices in HDR Television Production".

Table 1 illustrates the recommended conversions for a range of different signal types and applications.

Table 1 – Recommended Conversions and LUTs

	Signal	BBC LUT	Conversion Type		SDR to HDR		HDR to SDR	HDR to HDR
			Scene-Light	Display-Light	Direct Mapping	Up-Mapping	Down-Mapping	Trans-code
Graded Content	SDR graded inserts	5		✓		✓		
	SDR graded programmes	3		✓	✓			
	HLG graded content	8		✓			✓	
	PQ graded content	1 or 2		✓				✓
Camera to switcher	SDR BT.709 camera	6	✓			✓		
	S-Log3 camera	10	✓					✓
	"S-Log3 Live" camera	11	✓					✓
Camera to SDR shading	HDR only camera	8 or 12	✓	✓			✓	
Graphics	SDR matching colour branding	3		✓	✓			
	SDR matching in-vision signage	4	✓		✓			
Programme Output	SDR complete programme	8		✓			✓	
	SDR "Clean Feed" for mixing with unilateral and ISO SDR cameras	12	✓				✓	
	PQ for onward distribution	7		✓				✓

Extending the SDR Colour Gamut

When matching SDR BT.709 cameras with BT.2100 HLG cameras, significantly better results can be obtained if the signal clippers on the SDR cameras are relaxed to EBU Technical Recommendation R103 signal levels (-5%/+105%) and the conversion process takes account of the signals in the sub-blacks and super-whites. The sub-black and super-white signals produced by many cameras effectively increase the dynamic range and colour gamut of the camera. More details can be found in ITU-R report BT.2250.

In order to exploit the extended SDR signal range, the conversion LUT has to operate in "full-range" mode, taking account of the black level offset of the SDR input signals (10-bit code value 64) (LUT

Type III). Because of the improved performance, the scene-referred BT.709 to BT.2100 HLG direct mapping LUT (LUT 4) and up-mapping LUTs (LUT 6-1 and 6-2), are only provided in full-range mode (Type III) versions.

Output Signal Clipping

Output signals for Type I LUTs are clipped to the range 0 to 1. Type III LUTs with SDR BT.709 outputs are clipped within the look-up table to [EBU Technical Recommendation R103] signal levels. In territories with stricter limits on the SDR signal range, an additional hardware legaliser may be needed.

The remaining Type II and Type III LUTs with PQ or HLG outputs are clipped to full-range, to ensure that they pass ITU-R BT.2111 HDR Colour Bars. External processing, illustrated in Figures 2 and 3, is necessary to clip the LUT output to 10-bit SDI range (4 to 1019).

Colour Matrices

Older hardware based LUT devices assume BT.709 colour when converting between the $Y'C'_BC'_R$ signals carried on SDI interfaces and the R′G′B′ signals required by the look-up tables. When no option is available to select the correct BT.2020/BT.2100 colour matrix for the HDR signals, a correction can be applied within the look-up table itself, illustrated in Figure 6. Tables 4a, 4b and 4c indicate whether a LUT file includes the BT.709 colour matrix compensation.

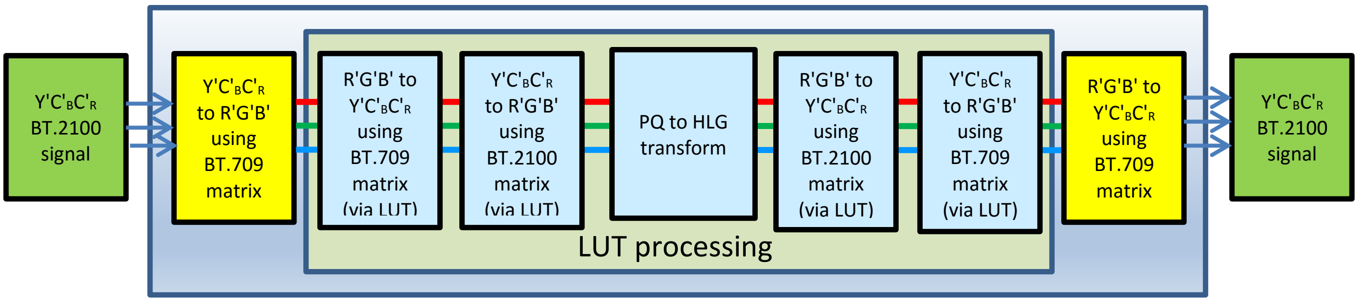

Figure 6 - Example of colour matrix compensation within a LUT. This example shows a PQ to HLG conversion

Software packages that support conversion LUTs, such as colour grading software, can usually be configured to use the correct BT.2020/BT.2100 colour primaries, normalise full-range and narrow-range input signals to a common range for their internal processing, and clip super-white and sub-black signals to lie within that range. So only a single Type I LUT (which is the same as the "narrow mode" hardware LUT without BT.709 colour matrix compensation) is necessary for most software applications.

LUTs for Testing Hardware

In order to test that LUT hardware is correctly configured, we have developed four special LUTs (13a, 13b, 13c & 13d) that can be used to confirm the correct input/output scaling and colour matrix processing. LUTs 13b, 13c & 13d output a fixed RGB triplet for any input value. They are used to confirm the LUT output-side processing. LUT 13a is a "pass-though" LUT. Once the output-side processing is known to be correct, the pass-through LUT can be used to confirm complementary processing on the input-side. When both input and output colour matrices are configured for the same colour space (BT.709 or BT.2020/BT.2100) and scaling, signals should pass through the LUT hardware almost transparently (with some interpolation errors) when loaded with the pass-through LUT 13a.

Particular care is necessary when configuring the LUT hardware as the scaling of C'_B and C'_R colour components is different for full-range and narrow-range BT.2100 signals (see Table 9 of ITU-R BT.2100). All BBC LUTs output narrow range signals, even when the LUT is operating in full-range mode. So, the narrow-range $Y'C'_BC'_R$ colour matrix equations should always be used for outputs. LUTs 1c & 1d and 2c & 2d (Type II LUTs) are designed for full-range PQ inputs signals, but narrow-range output signals. So full-range matrix equations should be used on input, and narrow-range matrix equations should be used on the output . We have not yet developed a test for LUT hardware loaded with these LUTs.

Tables 2 and 3 illustrate the expected $Y'C'_BC'_R$ 10-bit code values (decimal) on the SDI output for different combinations of colour matrix and LUT mode. Rounding errors of +/- 1 lsb (least significant bit) should be expected.

Table 2 - Narrow range mode LUT output on $Y'C'_BC'_R$ SDI

LUT Filename	LUT Output Values			Type I - Narrow Range LUT Mode (10-bit decimal 64 - 940)					
				BT.2020/BT.2100 Colour			BT.709 Colour		
	R'	G'	B'	Y'	C'b	C'r	Y'	C'b	C'r
13b_static_0-0_0-5_1-0.cube	0.000	0.500	1.000	412	798	269	440	787	267
13c_static_0-4_0-5_0-6.cube	0.400	0.500	0.600	484	569	463	489	567	463
13d_static_0-125_0-5_0-875.cube	0.125	0.500	0.875	435	726	330	455	718	328

Table 3- Full range mode LUT output on $Y'C'_BC'_R$ SDI for narrow range signals

LUT Filename	LUT Output Values			TYPE III - Full Range LUT Mode (10-bit decimal 0 - 1023), Narrow Range Output Signals (10-bit decimal 64 - 940)					
				BT.2020/BT.2100 Colour			BT.709 Colour		
	R'	G'	B'	Y'	C'b	C'r	Y'	C'b	C'r
13b_static_0-0_0-5_1-0.cube	0.000	0.500	1.000	407	846	229	439	833	226
13c_static_0-4_0-5_0-6.cube	0.400	0.500	0.600	490	578	455	497	576	454
13d_static_0-125_0-5_0-875.cube	0.125	0.500	0.875	433	762	300	457	753	297

Licensing Options

Two licences are available. The first licence is intended for manufacturers wishing to either embed the LUTs within their products, or include the LUTs with their products. The second licence is intended for broadcasters and production facilities, where the LUTs are to be loaded into existing equipment or software tools.

Please email transfer.rd@bbc.co.uk for details.

Table 4a - LUT conversions and variants.

No.	From	To	Comment	Variant	LUT Type	LUT Cube Size	LUTs for hardware: LUT Mode	Input Signal Range	Output Signal Range	BT.709 colour matrix comp.	Nominal Range LUTs for software: BT.709 colour matrix comp.	Filename
1	PQ 1000	BT.2100 HLG	Type III recommended for hardware as they pass sub-blacks and super-whites (e.g. BT.2111 Colour Bars).	a	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	1a_PQ1000_HLG_mode-nar_in-nar_out-nar_nocomp-
				a65	I	65	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	1a65_PQ1000_HLG_mode-nar_in-nar_out-
				b	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	Yes		1b_PQ1000_HLG_mode-nar_in-nar_out-nar_withcomp-
				c	II	33	Full	Full	Narrow with super-whites	No		1c_PQ1000_HLG_mode-full_in-full_out-nar_nocomp-v1_3.cube
				d	II	33	Full	Full	Narrow with super-whites	Yes		1d_PQ1000_HLG_mode-full_in-full_out-nar_withcomp-v1_3.cube
				e	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		1e_PQ1000_HLG_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				f	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		1f_PQ1000_HLG_mode-full_in-nar_out-nar_withcomp-v1_3.cube
2	PQ 4000	BT.2100 HLG	Luminance down-mapping. Type III recommended for hardware as they pass sub-blacks and super-whites (e.g. BT.2111 Colour Bars).	a	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	2a_PQ4000_HLG_mode-nar_in-nar_out-nar_nocomp-
				a65	I	65	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	2a65_PQ4000_HLG_mode-nar_in-nar_out-
				b	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	Yes		2b_PQ4000_HLG_mode-nar_in-nar_out-nar_withcomp-
				c	II	33	Full	Full	Narrow with super-whites	No		2c_PQ4000_HLG_mode-full_in-full_out-nar_nocomp-v1_3.cube
				d	II	33	Full	Full	Narrow with super-whites	Yes		2d_PQ4000_HLG_mode-full_in-full_out-nar_withcomp-v1_3.cube
				e	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		2e_PQ4000_HLG_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				f	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		2f_PQ4000_HLG_mode-full_in-nar_out-nar_withcomp-v1_3.cube
3	BT.709	BT.2100 HLG	Display-referred direct mapping maintaining SDR "look". 100% SDR maps to 75 % HLG (HDR Reference White - see ITU-R BT.2408 and BT.2390). **Recommended for matching the displayed colour of SDR graphics**. Type III preferred for hardware as they pass sub-blacks and super-whites.	a	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	3a_BT709_HLG_DISPLAY_mode-nar_in-nar_out-
				a65	I	65	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	3a65_BT709_HLG_DISPLAY_mode-nar_in-
				b	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	Yes		3b_BT709_HLG_DISPLAY_mode-nar_in-nar_out-
				c	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		3c_BT709_HLG_DISPLAY_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				d	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		3d_BT709_HLG_DISPLAY_mode-full_in-nar_out-nar_withcomp-v1_3.cube
4-1	BT.709 (Square-root) See Annex 1	BT.2100 HLG	Scene-referred direct mapping. **Recommended for matching SDR graphics with in-vision branding**. 100% SDR maps to 75 % HLG (HDR Reference White - see ITU-R BT.2408 and BT.2390).	a	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		4-1a_BT709_HLG_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				b	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		4-1b_BT709_HLG_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube
4-2	**BT.709 (strict) See Annex 1**	**BT.2100 HLG**	**Scene-referred direct mapping. Recommended for matching SDR graphics with in-vision branding. 100% SDR maps to 75 % HLG (HDR Reference White - see ITU-R BT.2408 and BT.2390).**	**a**	**III**	**33**	**Full**	**Narrow with super-whites & sub-blacks**	**Narrow with super-whites & sub-blacks**	**No**		**4-2a_BT709_HLG_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube**
				b	**III**	**33**	**Full**	**Narrow with super-whites & sub-blacks**	**Narrow with super-whites & sub-blacks**	**Yes**		**4-2b_BT709_HLG_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube**

Table 4b - LUT conversions and variants.

							LUTs for hardware				Nominal Range LUTs for software	
No.	From	To	Comment	Variant	LUT Type	LUT Cube Size	LUT Mode	Input Signal Range	Output Signal Range	BT.709 colour matrix comp.	BT.709 colour matrix comp.	Filename
5	BT.709	BT.2100 HLG	Display-referred up-mapping for SDR "look". Recommended for graded content. Type III preferred for hardware as they pass sub-blacks and super-whites. Matched with LUT 8 (display-light "down-conversion"). 100 % SDR maps to 83 % HLG. 105% SDR maps to 87% HLG.	a	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	5a_BT709_HLG_UPCONVERT_DISPLAY_ mode-nar_in-nar_out-nar_nocomp-v1_3.cube
				a65	I	65	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	5a65_BT709_HLG_UPCONVERT_DISPLAY_ mode-nar_in-nar_out-nar_nocomp-v1_3.cube
				b	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	Yes		5b_BT709_HLG_UPCONVERT_DISPLAY_mode-nar_in-nar_out-nar_withcomp-v1_3.cube
				c	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		5c_BT709_HLG_UPCONVERT_DISPLAY_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				d	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		5d_BT709_HLG_DISPLAY_UPCONVERT_mode-full_in-nar_out-nar_withcomp-v1_3.cube
6-1	BT.709 (Square-root) See Annex 1	BT.2100 HLG	Scene-referred SDR to HDR up-mapping. Recommended for matching SDR and HDR cameras in live production. Matched with LUT 12-1 (scene-light "down-conversion"). 100% SDR maps to 79% HLG. 105% SDR maps to 83% HLG	a	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		6-1a_BT709_HLG_UPCONVERT_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				b	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		6-1b_BT709_HLG_UPCONVERT_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube
6-2	BT.709 (Strict) See Annex 1	BT.2100 HLG	Scene-referred SDR to HDR up-mapping. Recommended for matching SDR and HDR cameras in live production. Matched with LUT 12-2 (scene-light "down-mapping"). 100% SDR maps to 79% HLG. 105% SDR maps to 83% HLG	a	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		6-2a_BT709_HLG_UPCONVERT_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				b	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		6-2b_BT709_HLG_UPCONVERT_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube
7	HLG	PQ 1000	Type III recommended for hardware as they pass sub-blacks and super-whites (e.g. BT.2111 Colour Bars).	a	I	33	Narrow	Narrow	Narrow	No	No	7a_HLG_PQ1000_mode-nar_in-nar_out-nar_nocomp-
				b	I	33	Narrow	Narrow	Narrow	Yes		7b_HLG_PQ1000_mode-nar_in-nar_out-nar_withcomp-
				c	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		7c_HLG_PQ1000_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				d	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		7d_HLG_PQ1000_mode-full_in-nar_out-nar_withcomp-v1_3.cube
8	HLG	BT.709	Display-light down-mapping with colour volume management to preserve hue. Recommended for preserving the HDR "look" in SDR. Matched with LUT 5 (display-light "up-mapping"). HDR Reference White maps to 86% SDR.	a	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	8a_HLG_BT709_mode-nar_in-nar_out-
				a65	I	65	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	No	No	8a65_HLG_BT709_mode-nar_in-nar_out-
				b	I	33	Narrow/Nominal	Narrow/Nominal	Narrow/Nominal	Yes		8b_HLG_BT709_mode-nar_in-nar_out-
				c	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		8c_HLG_BT709_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				d	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		8d_HLG_BT709_mode-full_in-nar_out-nar_withcomp-v1_3.cube

Table 4c - LUT conversions and variants.

							LUTs for hardware				Nominal Range LUTs for software	
No.	From	To	Comment	Variant	LUT Type	LUT Cube Size	LUT Mode	Input Signal Range	Output Signal Range	BT.709 colour matrix comp.	BT.709 colour matrix comp.	Filename
10	S-Log3 (100%)	BT.2100 HLG	BT.2020 colour. 100% S-Log3 (90% reflectance) maps to 73 % HLG (see BT.2408).	a	II	33	Full	Full	Narrow with super-whites & sub-blacks	No	No	10a_S-Log3_100pc_HLG_mode-full_in-full_out-nar_nocomp-v1_3.cube
				b	II	33	Full	Full	Narrow with super-whites & sub-blacks	Yes		10b_S-Log3_100pc_HLG_mode-full_in-full_out-nar_withcomp-v1_3.cube
11	S-Log3 (200%)	BT.2100 HLG	Typical SR-Live. 200% S-Log3 (90% reflectance) maps to 73% HLG.	a	II	33	Full	Full	Narrow with super-whites & sub-blacks	No	No	11a_S-Log3_200pc_HLG_mode-full_in-full_out-nar_nocomp-v1_3.cube
				b	II	33	Full	Full	Narrow with super-whites & sub-blacks	Yes		11b_S-Log3_200pc_HLG_mode-full_in-full_out-nar_withcomp-v1_3.cube
12-1	HLG	BT.709 (square-root) See Annex 1	Scene-light down-mapping, with a hard RGB gamut clip. Recommended for matching the SDR camera CCU output in live production. Matched with LUT 6-1 (scene-light down-mapping). 79% HLG maps to 100% SDR. 83% HLG maps 10 105% SDR.	a	I	33	Narrow	Narrow	Narrow	No		12-1a_HLG_BT709_SCENE_mode-nar_in-nar_out-
				b	I	33	Narrow	Narrow	Narrow	Yes		12-1b_HLG_BT709_SCENE_mode-nar_in-nar_out-
				c	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	No		12-1c_HLG_BT709_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube
				d	III	33	Full	Narrow with super-whites & sub-blacks	Narrow with super-whites & sub-blacks	Yes		12-1d_HLG_BT709_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube
12-2	**HLG**	**BT.709 (strict) See Annex 1**	**Scene-light down-mapping, with a hard RGB gamut clip. Recommended for matching the SDR camera CCU output in live production. Matched with LUT 6-2 (scene-light down-mapping). 79% HLG maps to 100% SDR. 83% HLG maps 10 105% SDR.**	**a**	**I**	**33**	**Narrow**	**Narrow**	**Narrow**	**No**		**12-2a_HLG_BT709_SCENE_mode-nar_in-nar_out-**
				b	**I**	**33**	**Narrow**	**Narrow**	**Narrow**	**Yes**		**12-2b_HLG_BT709_SCENE_mode-nar_in-nar_out-**
				c	**III**	**33**	**Full**	**Narrow with super-whites & sub-blacks**	**Narrow with super-whites & sub-blacks**	**No**		**12-2c_HLG_BT709_SCENE_mode-full_in-nar_out-nar_nocomp-v1_3.cube**
				d	**III**	**33**	**Full**	**Narrow with super-whites & sub-blacks**	**Narrow with super-whites & sub-blacks**	**Yes**		**12-2d_HLG_BT709_SCENE_mode-full_in-nar_out-nar_withcomp-v1_3.cube**
13	For testing LUT hardware		Pass-through LUT	a	N/A	33	N/A	N/A	N/A	No		13a_pass-through.cube
			R=0.0, G=0.5, B=1.0	b	N/A	33	N/A	N/A	N/A	No		13b_static_0-0_0-5_1-0.cube
			R=0.0, G=0.5, B=1.0	c	N/A	33	N/A	N/A	N/A	No		13c_static_0-4_0-5_0-6.cube
			R=0.125, G=0.5, B=0.875	d	N/A	33	N/A	N/A	N/A	No		13d_static_0-125_0-5_0-875.cube
14	**PQ 1000 P3D65**	**HLG**	**For conversion of some Hollywood movie content to HLG**	**a**	**I**	**33**				**No**	**No**	**14a_PQ1000_DCI-P3_HLG_nocomp-v1_3.cube**
				a	**I**	**65**				**No**	**No**	**14a65_PQ1000_DCI-P3_HLG_nocomp-v1_3.cube**
15	**HLG**	**PQ 1000 P3D65**	**HLG to PQ 1000 for delivery to Netflix. Software workflows.**	**a**	**I**	**33**				**No**	**No**	**15a_HLG_PQ1000_DCI-P3_nocomp-v1_3.cube**
				a65	**I**	**65**				**No**	**No**	**15a65_HLG_PQ1000_DCI-P3_nocomp-v1_3.cube**
16	**HLG**	**PQ 110 X'Y'Z'**	**HLG to PQ 110 X'Y'Z' for HDR cinema projection**	**a**	**I**	**33**				**No**	**No**	**16a_HLG_PQ110_DCI-P3_nocomp-v1_3.cube**

Annex 1- LUT Details

LUT 1 - PQ 1000 cd/m^2 to BT.2100 HLG

BT.2100 PQ signals are converted to BT.2100 HLG at the 1000 cd/m^2 “bridge” condition, so that 1000 cd/m^2 PQ maps to 100% HLG. See ITU-R report BT.2390 Section 7.2. With Type III LUTs, PQ signals above 1000 cd/m^2 are mapped into the HLG “super-white” signal range up to a maximum of 1810 cd/m^2, corresponding to 109% HLG (10-bit code value 1019).

The table illustrates the expected output signals from an ideal converter presented with a BT.2111 PQ colour bar input. The table takes no account of the expected interpolation errors, nor the clipping that will arise in Type I (narrow range mode) LUTs.

LUT 1 - PQ 1000 cd/m^2 to HLG - SDI Clipping (4 to 1019)						
Input: BT.2100 PQ	**Output: BT.2100 HLG**					
BT.2111 PQ Bars	**R'**	**G'**	**B'**	**Y**	**Cb**	**Cr**
100% White	1.090	1.090	1.090	1019	512	512
100% Yellow	1.090	1.090	0.000	962	24	551
100% Cyan	0.000	1.090	1.090	768	648	24
100% Green	0.000	1.090	0.000	711	160	63
100% Magenta	1.090	0.000	1.090	372	864	961
100% Red	1.090	0.000	0.000	315	376	1000
100% Blue	0.000	0.000	1.090	121	1000	473
58% White	0.749	0.749	0.749	720	512	512
58% Yellow	0.751	0.751	0.000	683	176	539
58% Cyan	0.000	0.759	0.759	554	607	172
58% Green	0.000	0.761	0.000	516	266	198
58% Magenta	0.785	0.000	0.785	286	766	836
58% Red	0.792	0.000	0.000	246	413	867
58% Blue	0.000	0.000	0.839	108	888	482
40% Grey	0.414	0.414	0.414	427	512	512
−7% Step	-0.041	-0.041	-0.041	28	512	512
0% Step	0.000	0.000	0.000	64	512	512
10% Step	0.061	0.061	0.061	118	512	512
20% Step	0.141	0.141	0.141	187	512	512
30% Step	0.255	0.255	0.255	287	512	512
40% Step	0.414	0.414	0.414	427	512	512
50% Step	0.615	0.615	0.615	603	512	512
60% Step	0.780	0.780	0.780	748	512	512
70% Step	0.927	0.927	0.927	876	512	512
80% Step	1.067	1.067	1.067	999	512	512
90% Step	1.090	1.090	1.090	1019	512	512
100% Step	1.090	1.090	1.090	1019	512	512
109% Step	1.090	1.090	1.090	1019	512	512
58% BT.709 Yellow	0.742	0.749	0.290	695	307	526
58% BT.709 Cyan	0.548	0.743	0.754	671	541	424
58% BT.709 Green	0.525	0.742	0.272	640	328	431
58% BT.709 Magenta	0.711	0.280	0.772	434	679	688
58% BT.709 Red	0.708	0.266	0.129	391	395	715
58% BT.709 Blue	0.230	0.118	0.812	229	809	537
0% Black	0.000	0.000	0.000	64	512	512
−2% Black	-0.013	-0.013	-0.013	53	512	512
+2% Black	0.013	0.013	0.013	75	512	512
+4% Black	0.025	0.025	0.025	85	512	512

LUT 2 - PQ 4000 cd/m² to BT.2100 HLG

4000 cd/m² BT.2100 PQ signals are converted to BT.2100 HLG by first tone mapping to the 1000 cd/m² "bridge" condition, and then converting to HLG. The tone mapping is applied on the luminance component to avoid hue distortions. 4000 cd/m² PQ maps to 100% HLG. See ITU-R report BT.2390 Section 7.4. With Type III LUTs, PQ signals above 4000 cd/m² are mapped into the HLG "super-white" signal range.

The table illustrates the expected output signals from an ideal converter presented with a BT.2111 PQ colour bar input. The table takes no account of the expected interpolation errors.

Table to follow

LUT 3 – BT.709 to BT.2100 HLG, Direct Mapping (Display-Light)

BT.709 signals are directly mapped into BT.2100 HLG at the BT.2408 signal levels using a display-light (display-referred) conversion. The "look" of the original BT.709 content is therefore preserved on conversion. 100% SDR signal is mapped to 75% HLG (HDR Reference White).

The table illustrates the expected output signals for an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 3 BT.709 to HLG Direct Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	602	512	512
75% Yellow	578	331	523
75% Cyan	543	543	418
75% Green	515	358	424
75% Magenta	330	656	654
75% Red	292	428	672
75% Blue	171	746	523
40% Grey	336	512	512
15% Grey	152	512	512
0% Black	64	512	512
−2% Black	55	512	512
+2% Black	73	512	512
100% White	721	512	512

LUT 4-1 – BT.709 to BT.2100 HLG, Direct Mapping (Scene-Light)

For use with SDR cameras that approximate the BT.709 OETF with a square root

BT.709 signals are directly mapped into BT.2100 HLG at the BT.2408 signal levels using a scene-light (scene-referred) conversion. The "look" of the original BT.709 content is changed to match native BT.2100 HLG cameras. 100% SDR signal is mapped to 75% HLG (HDR Reference White).

The table illustrates the expected output signals for an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 4-1 BT.709 to HLG Direct Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP 219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	618	512	512
75% Yellow	593	327	524
75% Cyan	557	543	418
75% Green	528	354	423
75% Magenta	334	657	655
75% Red	294	428	673
75% Blue	170	744	523
40% Grey	376	512	512
15% Grey	181	512	512
0% Black	64	512	512
−2% Black	48	512	512
+2% Black	80	512	512
100% White	721	512	512

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LUT 4-2 – BT.709 to BT.2100 HLG, Direct Mapping (Scene-Light)

For use with SDR cameras that implement a strict BT.709 OETF

BT.709 signals are directly mapped into BT.2100 HLG at the BT.2408 signal levels using a scene-light (scene-referred) conversion. The "look" of the original BT.709 content is changed to match native BT.2100 HLG cameras. 100% SDR signal is mapped to 75% HLG (HDR Reference White).

NOTE: Unlike BT.2100 HLG, SDR cameras that implement a strict BT.709 OETF tend to crush detail in the shadows of a scene. That detail will become more visible after applying this conversion.

The table illustrates the expected output signals from an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 4-2 BT.709 to HLG Direct Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP 219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	619	512	512
75% Yellow	593	327	524
75% Cyan	558	543	418
75% Green	528	354	423
75% Magenta	334	657	656
75% Red	295	427	673
75% Blue	170	745	523
40% Grey	389	512	512
15% Grey	214	512	512
0% Black	64	512	512
−2% Black	11	512	512
+2% Black	117	512	512

100% White	721	512	512

LUT 5 – BT.709 to BT.2100 HLG, Inverse Tone Mapping (Display-Light)

BT.709 signals are inverse tone mapped (up-converted) to BT.2100 HLG using a display-light (display-referred) conversion. This LUT is designed to complement LUT 8 (BT.2100 HLG to BT.709 tone mapping - display-light) to reduce round-tripping losses (SDR to HDR to SDR conversion).

Whilst the ITU-R BT.2408 signal levels are taken into account, a modest boost is applied to the SDR highlights to better match natively produced HDR content. The LUT, however, attempts to preserve the artistic intent of the original BT.709 content. 100% SDR signal is inverse tone mapped to 83% HLG.

The table illustrates the expected output signals for an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 5 BT.709 to HLG Inverse Tone Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP 219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	653	512	512
75% Yellow	628	319	525
75% Cyan	595	543	418
75% Green	564	345	423
75% Magenta	364	666	668
75% Red	324	417	690
75% Blue	186	767	526
40% Grey	377	512	512
15% Grey	166	512	512
0% Black	64	512	512
−2% Black	53	512	512
+2% Black	75	512	512

100% White	756	512	512

LUT 6-1 – BT.709 to BT.2100 HLG, Inverse Tone Mapping (Scene-Light)

For use with SDR cameras that approximate the BT.709 OETF with a square root

BT.709 signals are inverse tone mapped (up-converted) to BT.2100 HLG using a scene-light (scene-referred) conversion. The “look” of the original BT.709 content is changed to match native BT.2100 HLG cameras. Whilst the ITU-R BT.2408 signal levels are taken into account, a small boost is applied to the SDR highlights to better match natively produced HDR content. 100% SDR signal is inverse tone mapped to 79% HLG. 105% SDR signals (EBU R.103 signal levels) are inverse tone-mapped to 83% HLG.

The table illustrates the expected output signals for an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 6-1 - BT.709 to HLG Inverse Tone Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP 219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	618	512	512
75% Yellow	593	327	524
75% Cyan	557	543	418
75% Green	528	354	423
75% Magenta	334	657	655
75% Red	294	428	673
75% Blue	170	744	523
40% Grey	376	512	512
15% Grey	181	512	512
0% Black	64	512	512
−2% Black	48	512	512
+2% Black	80	512	512
100% White	792	512	512

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LUT 6-2 – BT.709 to BT.2100 HLG, Inverse Tone Mapping (Scene-Light)

For use with SDR cameras that implement a strict BT.709 OETF

BT.709 signals are inverse tone mapped (up-converted) to BT.2100 HLG using a scene-light (scene-referred) conversion. The "look" of the original BT.709 content is changed to match native BT.2100 HLG cameras. Whilst the ITU-R BT.2408 signal levels are taken into account, a small boost is applied to the SDR highlights to better match natively produced HDR content. 100% SDR signal is inverse tone mapped to 79% HLG. 105% SDR signals (EBU R.103 signal levels) are inverse tone-mapped to 83% HLG.

NOTE: Unlike BT.2100 HLG, SDR cameras that implement a strict BT.709 OETF tend to crush detail in the shadows of a scene. That detail will become more visible after applying this conversion.

The table illustrates the expected output signals for an ideal converter presented with a SMPTE RP 219 colour bar input. The table takes no account of the expected interpolation errors.

LUT 6-2 - BT.709 to HLG Inverse Tone Mapping			
Input: BT.709	**Output: BT.2100 HLG**		
RP 219 75% Colour Bars	**Y'**	**C'_B**	**C'_R**
75% White	619	512	512
75% Yellow	593	327	524
75% Cyan	558	543	418
75% Green	528	354	423
75% Magenta	334	657	656
75% Red	295	427	673
75% Blue	170	745	523
40% Grey	389	512	512
15% Grey	214	512	512
0% Black	64	512	512
−2% Black	11	512	512
+2% Black	117	512	512

100% White	756	512	512

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LUT 7 - BT.2100 HLG to PQ 1000 cd/m²

BT.2100 HLG signals are converted to BT.2100 PQ at the 1000 cd/m² "bridge" condition, so that 100% HLG maps to 1000 cd/m² PQ. See ITU-R report BT.2390 Section 7.2. For Type III LUTs, HLG signals above 100% are mapped to PQ signals greater than 1000 cd/m², up to a maximum of 1810 cd/m², corresponding to 109% HLG (10-bit code value 1019).

The table illustrates the expected output signals from an ideal converter presented with a BT.2111 HLG colour bar input. The table takes no account of the expected interpolation errors.

LUT 7 - HLG to PQ 1000 cd/m² - SDI Clipping (4 to 1019)						
Input: BT.2100 HLG	**Output: BT.2100 PQ (Narrow Range)**					
BT.2111 PQ Bars	**R'**	**G'**	**B'**	**Y'**	**C'b**	**C'r**
100% White	0.752	0.752	0.752	723	512	512
100% Yellow	0.750	0.750	0.000	682	176	539
100% Cyan	0.000	0.745	0.745	545	605	178
100% Green	0.000	0.743	0.000	506	272	206
100% Magenta	0.727	0.000	0.727	269	747	812
100% Red	0.723	0.000	0.000	230	422	836
100% Blue	0.000	0.000	0.690	100	821	487
75% White	0.581	0.581	0.581	573	512	512
75% Yellow	0.579	0.579	0.000	542	252	533
75% Cyan	0.000	0.574	0.574	435	584	255
75% Green	0.000	0.573	0.000	404	327	276
75% Magenta	0.557	0.000	0.557	221	692	742
75% Red	0.553	0.000	0.000	191	443	760
75% Blue	0.000	0.000	0.523	91	746	493
40% Grey	0.392	0.392	0.392	407	512	512
−7% Step	-0.111	-0.111	-0.111	-33	512	512
0% Step	0.000	0.000	0.000	64	512	512
10% Step	0.154	0.154	0.154	199	512	512
20% Step	0.256	0.256	0.256	288	512	512
30% Step	0.332	0.332	0.332	355	512	512
40% Step	0.392	0.392	0.392	407	512	512
50% Step	0.442	0.442	0.442	451	512	512
60% Step	0.492	0.492	0.492	495	512	512
70% Step	0.549	0.549	0.549	545	512	512
80% Step	0.613	0.613	0.613	601	512	512
90% Step	0.681	0.681	0.681	661	512	512
100% Step	0.752	0.752	0.752	723	512	512
109% Step	0.817	0.817	0.817	779	512	512
75% BT.709 Yellow	0.574	0.578	0.361	558	415	518
75% BT.709 Cyan	0.476	0.569	0.574	541	526	470
75% BT.709 Green	0.462	0.565	0.342	523	425	474
75% BT.709 Magenta	0.514	0.319	0.545	400	589	591
75% BT.709 Red	0.502	0.302	0.200	369	442	605
75% BT.709 Blue	0.251	0.166	0.515	247	658	537
0% Black	0.000	0.000	0.000	64	512	512
−2% Black	-0.029	-0.029	-0.029	39	512	512
+2% Black	0.029	0.029	0.029	89	512	512
+4% Black	0.067	0.067	0.067	122	512	512

LUT 8 – BT.2100 HLG to BT.709, Tone Mapping (Display-Light)

BT.2100 HLG signals are tone mapped (down-converted) to BT.709 using a display-light (display-referred) conversion. The LUT, therefore, attempts to preserve the artistic intent of the original HLG content, when converting to SDR. This LUT is designed to complement LUT 5 (BT.709 to BT.2100 HLG inverse tone mapping - display-light) to reduce round-tripping losses (SDR to HDR to SDR conversion).

HDR Reference White (75% HLG) is tone mapped to 86% BT.709, allowing signal headroom for compressed highlights. 100% HLG signal is tone mapped to 100% BT.709. With Type III LUTs that process sub-blacks and super-whites, the HLG super-white signals are tone-mapped to SDR super-white signals. The LUT outputs are clipped to EBU R.103 signal levels.

The table (over page) illustrates the expected output signals for an ideal converter presented with the HDR “Line-Up” Bars described in Annex 2 and segments from BT.2111 HLG Colour Bars. The table takes no account of the expected interpolation errors. For saturated colour bar signals, these might be as high as +/- 3% for a 33-cube LUT. Errors should be lower and less noticeable on normal pictures.

NOTE: BT.2111 HLG colour bars will not look like standard BT.709 colour bars after conversion as the BT.2100 colour primaries are quite different from BT.709. The converted colour bars will also not look like BT.2111 colour bars displayed on a current reference display, as their colour primaries tend to be closer to P3 than BT.2100.

Annex 2 Line-Up Colour Bars	LUT 8 EBU R.103 Clipping BT.709 D' Decimal Y	C'_B	C'_R
Display Light			
DL White	649	511	512
DL Yellow	606	212	539
DL Cyan	524	580	212
DL Green	482	281	240
DL Magenta	230	742	783
DL Red	188	443	811
DL Blue	106	810	484
Scene-Light			
SL White	671	511	512
SL Yellow	626	201	540
SL Cyan	540	582	202
SL Green	495	274	231
SL Magenta	232	745	787
SL Red	189	442	813
SL Blue	105	807	484
BT.2111	**Y**	**C'_B**	**C'_R**
40% Grey	451	512	512
0% Black	64	512	512
−2% Black	37	511	511
+2% Black	90	512	512
+4% Black	116	512	512

LUT 10 – Sony S-Log3 (100%) to BT.2100 HLG (Scene-Light)

S-Log3 signals produced using the Sony's "100 %" workflow (i.e. 100% IRE input equals 90% reflectance) are converted to BT.2100 HLG with ITU-R BT.2408 signal levels. Thus a 100% IRE input signal (90% reflectance) maps to 73% HLG.

A scene-light conversion is used, so that the converted S-Log3 signal matches the "look" of BT.2100 HLG cameras.

LUT 11 – Sony S-Log3 (200%) to BT.2100 HLG (Scene-Light)

S-Log3 signals produced using the Sony's "200 %" workflow (i.e. 200% IRE input equals 90% reflectance) are converted to BT.2100 HLG with ITU-R BT.2408 signal levels. Thus a 200% IRE input signal (90% reflectance) maps to 73% HLG. 200% workflows are common for "S-Log3 Live" productions.

A scene-light conversion is used, so that the converted S-Log3 signal matches the "look" of BT.2100 HLG cameras.

LUT 12-1 – BT.2100 HLG to BT.709, Tone Mapping (Scene-Light)

For use with SDR cameras that approximate the BT.709 OETF with a square root

BT.2100 HLG signals are tone mapped (down-converted) to BT.709 using a scene-light (scene-referred) conversion. The "look" of the original BT.2100 HLG content is changed to match native BT.709 cameras with a square root approximation of the BT.709 OETF.

This LUT is the exact inverse of LUT 6-1 (BT.709 to BT.2100 HLG inverse tone mapping - scene-light) to minimise round-tripping losses (SDR to HDR to SDR conversion).

HDR Reference White (75% HLG) is tone mapped to 95% BT.709, allowing for some soft clipping of highlights. 79% HLG signal is tone mapped to 100% BT.709. With Type III LUTs that process sub-blacks and super-whites, the LUT outputs are clipped to EBU R.103 signal levels.

The table illustrates the expected output signals for an ideal converter presented with the HDR "Line-Up" Bars described in Annex 2 and segments from BT.2111 HLG Colour Bars. The table takes no account of the expected interpolation errors. For saturated colour bar signals, these might be as high as +/- 3% for a 33-cube LUT. Errors should be lower and less noticeable on normal pictures.

	LUT 12-1 EBU R.103 Clipping		
BT.2100 HLG input	**BT.709 Output**		
Line-Up Colour Bars	**Y**	**C'B**	**C'R**
Display Light			
DL White	693	512	512
DL Yellow	648	189	541
DL Cyan	562	586	188
DL Green	517	262	217
DL Magenta	248	766	812
DL Red	202	435	844
DL Blue	112	852	480
Scene-Light			
SL White	721	512	512
SL Yellow	673	175	542
SL Cyan	581	588	176
SL Green	533	252	206
SL Magenta	251	771	817
SL Red	203	435	847
SL Blue	111	848	481
BT.2111 Bars	**Y**	**C'B**	**C'R**
40% Grey	456	512	512
0% Black	64	512	512
−2% Black	46	511	511
+2% Black	81	512	512
+4% Black	103	512	512

LUT 12-2 – BT.2100 HLG to BT.709, Tone Mapping (Scene-Light)

For use with SDR cameras that implement a strict BT.709 OETF

BT.2100 HLG signals are tone mapped (down-converted) to BT.709 using a scene-light (scene-referred) conversion. The "look" of the original BT.2100 HLG content is changed to match native BT.709 cameras with a strict implementation of the BT.709 OETF.

This LUT is the exact inverse of LUT6-2 (BT.709 to BT.2100 HLG inverse tone mapping - scene-light) to minimise round-tripping losses (SDR to HDR to SDR conversion).

HDR Reference White (75% HLG) is tone mapped to 95% BT.709, allowing for some soft clipping of highlights. 79% HLG signal is tone mapped to 100% BT.709. With Type III LUTs that process sub-blacks and super-whites, the LUT outputs are clipped to EBU R.103 signal levels.

NOTE: Unlike BT.2100 HLG, SDR cameras that implement a strict BT.709 OETF tend to crush detail in the shadows of a scene. So shadow detail visible in the HDR image will become less visible after applying this conversion

The table (over page) illustrates the expected output signals for an ideal converter presented with the HDR "Line-Up" Bars described in Annex 2 and segments from BT.2111 HLG Colour Bars. The table takes no account of the expected interpolation errors. For saturated colour bar signals, these might be as high as +/- 3% for a 33-cube LUT. Errors should be lower and less noticeable on normal pictures.

Annex 2 Line-Up Colour Bars	LUT 12-2 EBU R.103 Clipping BT.709 Output Y	C'B	C'R
Display Light			
DL White	692	512	512
DL Yellow	647	190	541
DL Cyan	561	585	189
DL Green	516	262	218
DL Magenta	247	766	811
DL Red	202	435	844
DL Blue	112	852	480
Scene-Light			
SL White	720	512	512
SL Yellow	672	176	542
SL Cyan	580	588	176
SL Green	533	253	207
SL Magenta	250	770	816
SL Red	203	435	847
SL Blue	111	847	481
BT.2111 Bars	**Y**	**C'B**	**C'R**
40% Grey	444	512	512
0% Black	64	512	512
−2% Black	62	511	511
+2% Black	65	512	512
+4% Black	71	512	512

Annex 2 – Preliminary HDR "Line-Up" Bars

Whilst the ITU-R BT.2111 Colour Bars work well for ensuring the integrity of HDR signal paths, they were never designed to be used with HDR to SDR format conversion. The wide colour gamut bars in the upper portion of the test pattern extend beyond the capabilities of current HDR displays, so they are seldom displayed with the correct hue. That makes it difficult to judge how they should be appear after conversion to SDR BT.709. In addition, the BT.709 bars within the lower portion of the test pattern are inserted at 100% of the "HDR "Reference White" signal level. Signals in that region are usually affected by any HDR to SDR tone-mapping curve, which changes their luminance dependant on the colour. They will not, therefore, land on the colour targets of a vectorscope.

Instead, for testing end-to-end signal chains that include HDR to SDR format conversion, the BBC recommends using BT.709 colour bars inserted into an HDR test pattern at 75% of the HDR "Reference White" level, so that they are well within the BT.709 colour volume. They are then less likely to be affected by HDR to SDR format conversion and should resemble standard 75% BT.709 Colour Bar. So operational staff will be familiar with how they should appear on screen and how they should be measured with BT.709 test equipment.

To allow testing of both scene-light and display-light HDR to SDR format conversion, the 75% BT.709 bars are directly mapped into an HDR test pattern using both scene-light and display-light conversion methods. The table below specifies the proposed HLG HDR signal levels for the 75% Graphics White BT.709 "Line-Up" Bars.

Line-Up Colour Bars	**BT.2100 HLG**					
75% Graphics White BT.709 Bars	**R'**	**G'**	**B'**	**Y'**	**C'b**	**C'r**
Display Light						
DL White	602	602	602	602	512	512
DL Yellow	594	601	246	578	331	523
DL Cyan	408	591	601	543	543	418
DL Green	388	589	232	515	358	424
DL Magenta	534	227	595	330	656	654
DL Red	522	216	138	292	428	672
DL Blue	187	127	602	171	746	523
Scene-Light						
SL White	618	618	618	618	512	512
SL Yellow	610	616	253	593	327	524
SL Cyan	422	605	615	557	543	418
SL Green	400	603	238	528	354	423
SL Magenta	541	230	601	334	657	655
SL Red	527	218	139	294	428	673
SL Blue	186	126	598	170	744	523

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Revision History

LUT Release	Date	Comments
1.0	22/12/17	• Initial release
1.1	27/03/18	• Adds S-Log3 to HLG conversion • Adds several Type III LUTs to pass sub-blacks and super-whites • Corrects a small black level offset for PQ LUTs 1c, 1d and 2c, 2d, 7a and 7b
1.2	20/07/18	• SDR scene-light mapping to HLG (LUT 4) now maps 100% SDR to 75% HLG rather than 73%, to align with recommendations in ITU-R Report BT.2390. • Improves the “round-tripping” performance of the display-light SDR to HLG up-mapping (LUT 5) and HLG to SDR down-mapping (LUT 8). • Improves the colour space conversion of the display-light HLG to SDR down-mapping (LUT 8) • Adds LUT 12 for scene-light HLG to SDR conversion, to mimic the SDR output of a camera CCU. • Adds LUTs 13a, 13b, 13c and 13d for testing LUT hardware. • Minor improvement to the accuracy of all full-range LUT conversions.
1.3	09/04/2019	• Reduced hue shifts in the HLG to SDR BT.709 display-light conversion; • Adds scene-light LUTs for different types of SDR cameras (square root and strict BT.709 OETFs); • Reduces the scene-light inverse tone mapping signal level to cope with a wider range of SDR signals in live production; • Adds conversions to/from PQ with P3D65 colorimetry; • Adds 65-cube LUTs for critical workflows; • Adds an HLG to HDR X′Y′Z′ PQ 110 cd/m^2 HDR projector LUT.
1.3.1	20/06/2019	• Corrects a sub-black clipping problem in LUT 8c