

Guidance on Format Conversion in HLG Production

Part of the [HDR-TV](#) series. Last updated April 2020.

These notes should be read in conjunction with the “[Release Notes for HLG Format Conversion LUTs](#)” (currently version 1.4) and the “[Implementation Guidelines for HLG Format Conversion LUTs](#)”.

Introduction

To facilitate the introduction of ITU-R Recommendation [BT.2100](#) Hybrid Log-Gamma (HLG) production, BBC R&D are licensing a package of look-up tables (LUTs) that 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 comprise:

- Display-light conversions, which preserve the colour and appearance of content after conversion:
 - BT.2100 Perceptual Quantization (PQ) 1000 cd/m² nominal peak-luminance signals to BT.2100 HLG
 - BT.2100 PQ 4000 cd/m² nominal peak-luminance signals to BT.2100 HLG
 - BT.2100 HLG to BT.2100 PQ 1000 cd/m² nominal peak-luminance
 - [BT.709](#) (SDR) to BT.2100 HLG “direct-mapping”, preserving the appearance of SDR
 - BT.709 (SDR) to BT.2100 HLG “up-mapping”, slightly increasing the contrast in the SDR image to better match the appearance of “native” HDR content
 - BT.2100 HLG to BT.709 “down-mapping”, preserving the “look” of the HDR content (colour, lowlights and mid-tones) as it is converted to SDR
 - PQ P3D65 1000 cd/m² nominal peak-luminance to BT.2100 HLG
 - BT.2100 HLG to PQ P3D65 1000 cd/m² nominal peak-luminance
 - BT.2100 HLG to PQ 110 cd/m² nominal peak-luminance X'Y'Z' (HDR movie)
- Scene-light conversions, which should be used for colour-matching cameras in live production:
 - BT.709 (SDR) to BT.2100 HLG “direct-mapping”, for colour-matching SDR and HLG cameras

- BT.709 (SDR) to BT.2100 HLG “up-mapping”, for colour-matching SDR and HLG cameras but with a small highlights “boost” to complement the visual characteristics of HDR cameras
 - BT.2100 HLG to BT.709 (SDR) “down-mapping” to match the colour and “look” of downstream SDR cameras
 - Sony [S-Log3](#) and S-Log3 [SR Live](#) ([BT.2020](#) colour) to BT.2100 HLG, thereby matching the colour and “look” of BT.2100 HLG cameras
- Test LUTs to verify the correct operation of LUT hardware.

More details on the different types of conversion can be found in ITU-R Report [BT.2408](#), Section 5 (“Inclusion of standard dynamic range content”). In addition to these guidelines, Section 7 of the report provides examples of how the different types of conversion can be used in practice.

The scene-light LUTs will only colour-match ITU-R BT.2100 HLG and BT.709 cameras. They will not colour-match HDR cameras configured for Sony’s “HLG Live” variants, nor the “Traditional Colour” variant of HLG specified in ITU-R report [BT.2390](#) (which is sometimes referred to as “HLG Vivid”). Should more “colourful” HDR images be preferred, we recommend using the standard BT.2100 HLG and adding colour-saturation to signals with the camera’s painting controls. By doing so, and adding a similar amount of saturation to the SDR cameras, a good colour-match can usually be achieved between the different camera types via conventional scene-light conversions such as these.

As part of the LUT package, we also offer (on request) a 65-cube 3D-LUT for loading into a Dolby PRM-4200/4220 display. This adds support for BT.2100 HLG.

Scene-Light vs Display-Light Conversions

To appreciate the difference between a scene-light and display-light format conversion, it is helpful to consider the end-to-end “live” television chain, illustrated in Figure 4 (over page):

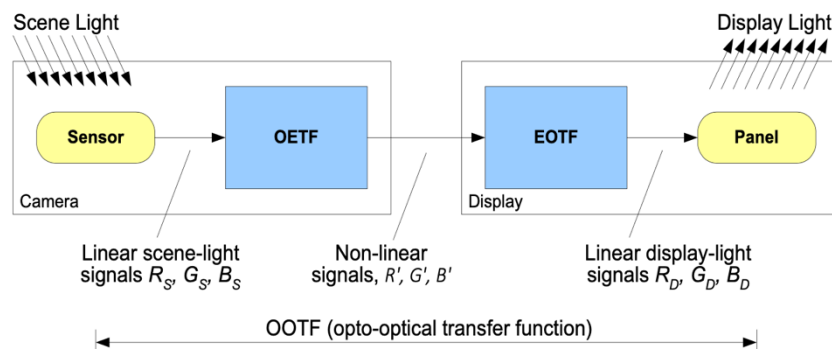


Figure 4- Simplified Live-TV Chain

Light collected by the camera lens is focused onto the camera sensor, and converted into three linear light signals, R_S , G_S and B_S . Since their levels are proportional to the red, green and blue light falling on the camera sensors, these linear signals are also referred to as “scene-light” signals. They are then in turn converted to non-linear signals R' , G' , B' , using the camera’s opto-electronic transfer function (OETF) – the ‘prime’ symbols denote non-linear signals. The OETF improves the noise performance of the end-to-end chain, by providing a better match between the noise introduced by quantisation in the production chain and human visual perception. The R' , G' , B' signals are then passed to the display, where an electro-optical transfer function (EOTF) converts the non-linear signals to the linear display-light signals R_D , G_D , B_D feeding the panel.

Overall the TV system has a non-linear “opto-optical transfer function” (OOTF), which is the concatenation of the camera OETF and display EOTF. The OOTF is designed to ensure that the displayed pictures are subjectively similar to the scene in front of the camera. This is achieved by compensating for changes in the response to light of the human visual system, as the eye adapts to its surroundings and different display peak-luminances.

Many SDR/HDR format conversions are based on “display-light”. Here, the conversion calculates the light produced by the original signal on a reference-display (represented by R_D , G_D , B_D above) operating in the original format. The conversion then attempts to achieve 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. Display-light conversions are thus effective for graded content and graphics, where it is important to retain the original colours and

relative tones. An example of a display-light conversion for BT.709 to BT.2100 HLG is shown in Figure 5 below:

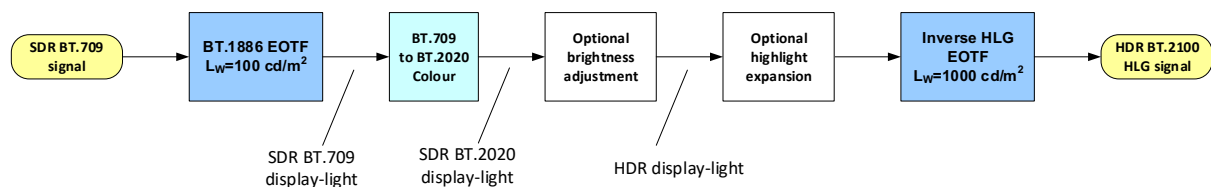


Figure 5 - SDR to HDR Display-Light Conversion

Within the conversion process, the BT.709 input signal is passed to a model of a [BT.1886](#) SDR reference display. A matrix then converts the red, green and blue BT.709 display-light signals to red, green, blue BT.2020 colour-primary signals. Under some circumstances, the SDR BT.2020 display-light signals might then have their brightness adjusted to better-match HDR signals. The final stage is the application of an 'inverse HLG EOTF', to create the HLG signal itself.

For live production, however, it is usually more important to colour-match the signals produced by cameras operating in different formats after conversion – to, for example, colour-match an SDR BT.709 super “slo-mo” camera to a native BT.2100 HLG camera. In terms of colour and tone reproduction, though, the native-displayed “look” of the SDR BT.709 and BT.2100 HLG production formats - and indeed all other formats including PQ, BT.2020 and S-Log3 SR Live - are different. This is because each format has a different OOTF. Colour matching of cameras will, as a result, be difficult if display-light conversions are employed. A scene-light conversion should instead be used, as their calculations are based on the light falling on the camera-sensor and therefore independent of a format’s OOTF.

An example of a scene-light conversion for BT.709 to BT.2100 HLG is shown in Figure 6 (over page). A scene-light conversion calculates the light falling on the camera sensor by applying an inverse-OETF to the input signal. It then applies any colour-space conversion and highlight-expansion before deriving 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 closer match in terms of colour and tone is obtained than would be possible through display-light conversion.

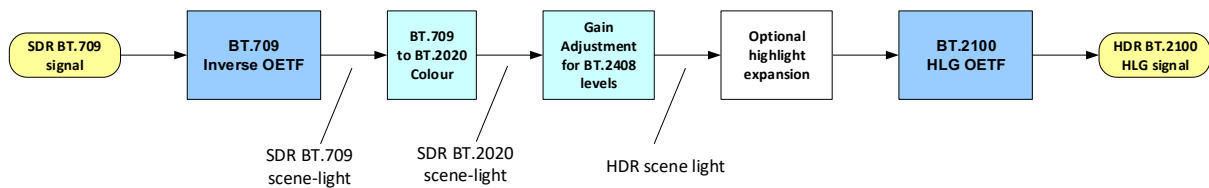


Figure 6 - Scene-light SDR-to-HDR conversion

In practice, cameras will usually have artistic adjustments applied through “painting controls” to deliver the desired “look”. Provided the SDR and HDR cameras have similar painting controls available, a good colour and tone match is usually still possible, as the painting controls can be thought of as adjusting the light within the natural scene, before it hits the camera sensor.

Scene-light conversions are also useful for HDR-to-SDR conversion, where the goal is to match the “look” of a traditional SDR camera. A common example is where a “host” broadcaster needs to provide an SDR feed to other broadcasters covering the same event. These third-party broadcasters may need to inter-cut the host feed with signals from their own SDR cameras.

However, scene-light conversions should only be used on “clean” feeds (without graphics) as the hue, saturation and tone will differ slightly from the HDR original signal. Most often, reds will appear more saturated after a scene-light HDR to SDR conversion, and the mid-tones may appear slightly darker. As graphics are often carefully designed to match coloured branding, it is usually important to preserve their colour after conversion. For that reason, display-light conversions are recommended whenever graphics are present.

More details can be found in section 7.1.3 (“Guidance for Operational Practices in HDR Television Production”) of ITU-R report BT.2408. The full set of format conversion LUTs provided at the time of writing is given below in Table 1.

Table 1 – Licensed Conversion LUTs

BBC LUT Number	Conversion
1	BT.2100 PQ 1000 cd/m2 to BT.2100 HLG
2	BT.2100 PQ 4000 cd/m2 to BT.2100 HLG
3	BT.709 to BT.2100 direct-mapping (display-light)
4	BT.709 to BT.2100 direct-mapping (scene-light)
5	BT.709 to BT.2100 up-mapping (display-light)
6	BT.709 to BT.2100 up-mapping (scene-light)
7	BT.2100 HLG to BT.2100 PQ 1000 cd/m2
8	BT.2100 HLG to BT.709 down-mapping (display-light)

BBC LUT Number	Conversion
9	BT.2100 HLG to BT.709 down-mapping (display-light) with SDR super-whites ¹
10	S-Log3 (BT.2020) to BT.2100 HLG (scene-light)
11	S-Log3 “SR Live” to BT.2100 HLG (scene-light)
12	BT.2100 HLG to BT.709 down-mapping (scene-light)
13	Test LUTs
14	PQ P3D65 1000 cd/m ² to BT.2100 HLG
15	BT.2100 HLG to PQ P3D65 1000 cd/m ²
16	BT.2100 HLG to X'Y'Z' PQ at 108 cd/m ²

More conversions may be added in the future.

Use of the Conversion LUTs in HDR-TV Production

A BBC R&D [blog](#) describes how these different types of conversions were used for BBC Sport's coverage of the 2019 FA Cup Final. Table 2 (over page) summarises the recommended conversions for a range of different signal types and applications. As a general rule:

- Anything relating to cameras requires a scene-light conversion, as the job of a camera is to capture the light in the scene.
- Anything relating to graphics or graded content requires a display-light conversion, as it is important to maintain the displayed “look” of graphics and graded content after conversion.

SDR-graded content (e.g. movies and drama) has usually been carefully captured and processed to avoid over-exposed areas of the picture. As a result, display-light up-mapping is able to provide more highlight “boost” than the equivalent “scene-light” up-mapping when converting from SDR to HDR. The amount of highlight-boost provided by scene-light up-mapping is deliberately limited. This is to prevent clipped/over-exposed highlights (e.g. skies), as commonly encountered in live SDR production, from ending up as large overly-bright areas within the resulting HDR image.

¹ signals above nominal peak-white (BT.709 10-bit code value 940)

Table 2 – 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	3		✓	✓			
	HLG graded content	8		✓			✓	
	PQ graded content	1 or 2		✓				✓
Camera to switcher	SDR BT.709 camera	4 or 6	✓		✓ ¹	✓ ¹		
	S-Log3 camera	10	✓					✓
	"S-Log3 Live" camera	11	✓					✓
Camera to SDR shading	HDR-only camera	8, 9 or 12	✓	✓			✓	
Graphics	SDR matching colour branding	3		✓	✓			
	SDR matching in-vision signage. Seldom used.	4	✓		✓			
Programme Output	SDR complete	8 or 9		✓			✓	
	SDR "Clean Feed" for mixing with unilateral	12	✓				✓	
	PQ for onward distribution	7		✓				✓

Note 1: Dependent on the capabilities and performance of the SDR camera

LUT Pairing for “Round-Tripping”

Early HDR trial productions used parallel HDR/SDR production workflows. But as we migrate towards single HDR production workflows feeding both HDR and SDR delivery chains, the majority

of live productions will rely on multiple and cascaded format-conversions. In the FA Cup coverage described in the aforementioned blog-post:

- Graphics were created in SDR BT.709, directly-mapped into HLG HDR for the HDR production-switcher, and down-mapped back to SDR BT.709 for distribution on HD SDR channels;
- SDR edited packages were up-mapped to HDR for the production switcher, subsequently being down-mapped back to BT.709 for SDR distribution;
- SDR cameras were up-mapped to HDR for the production switcher, and down-mapped back to BT.709 for SDR distribution;
- Similarly, the up-mapped SDR cameras were then down-mapped back to SDR for shading ('racking') on an SDR monitor;
- Even HDR cameras were down-mapped to SDR BT.709 for replay-server recording, and then up-mapped back to HDR on the replay-server output feeding the production-switcher. This was then again down-mapped back to BT.709, for SDR distribution.

Cascaded SDR-to-HDR and HDR-to-SDR conversions are known as "round-trip" conversions. Unfortunately, the very best SDR-to-HDR conversion is seldom the exact inverse of the best HDR-to-SDR conversion. As a result, "round-tripping" often results in losses that, although unavoidable, can usually be managed to avoid significant deterioration. To minimise such losses, the following LUT "pairings" are recommended:

Display-Light Pairings

For SDR distribution chains that might not pass super-whites, use LUT8 for HDR-to-SDR down-mapping (100% HLG > 100% SDR):

Graded inserts - small round-trip loss, 100% SDR > 93% SDR:

- SDR/HDR up-mapping > HDR/SDR down-mapping
 - Up-mapping LUT 5 (100% SDR > 82% HLG)
 - Down-mapping LUT 8 (82% HLG > 93% SDR)

Graphics - small round-trip loss, 100% SDR > 90% SDR:

- SDR/HDR direct-mapping > HDR/SDR down-mapping
 - Direct-mapping LUT 3 (100% SDR > 75% HLG)
 - Down-mapping LUT 9 (75% HLG > 90% SDR)

For SDR distribution chains that pass super-whites, use LUT9 for HDR-to-SDR down-mapping (100% HLG > 107% SDR):

Graded inserts - minimal round-trip distortion in upper mid-tones, 100% SDR > 100% SDR:

- SDR/HDR up-mapping > HDR/SDR down-mapping (with super-whites)
 - Up-mapping LUT 5 (100% SDR > 82% HLG)
 - Down-mapping LUT 9 (82% HLG > 100 % SDR)

Graphics - small round-trip loss, 100% SDR > 95% SDR:

- SDR/HDR direct-mapping > HDR/SDR down-mapping (with super-whites)
 - Direct-mapping LUT 3 (100% SDR > 75% HLG)
 - Down-mapping LUT 9 (75% HLG > 95% SDR)

Scene-Light Pairings

Use LUT12 for all HDR-to-SDR down-mapping (100% HLG > 105% SDR):

High-quality SDR cameras – near-lossless round-trip, 100% SDR > 100% SDR:

- SDR/HDR up-mapping > HDR/SDR down-mapping
 - Up-mapping LUT 6 (100% SDR > 79% HLG)
 - Down-mapping LUT 12 (79% HLG > 100 % SDR)

Poorer-quality SDR cameras - small round-trip loss, 100% SDR > 95% SDR:

- SDR/HDR direct-mapping > HDR/SDR down-mapping (with super-whites)
 - Direct-mapping LUT 4 (100% SDR > 75% HLG)
 - Down-mapping LUT 12 (75% HLG > 95% SDR)

Camera Shading

For live production, we recommend shading (or “racking”) both HDR and up-mapped SDR cameras via the same HDR-to-SDR down-mapping LUT that one would use to derive the SDR programme output. That way, video engineers will be delivering optimal SDR pictures to current majority

audiences. The resulting HDR signal may not exploit the full potential of HDR, but it can nevertheless deliver stunning images that represent a significant improvement over SDR.

For the 2019 FA Cup trial, it made little difference whether we shaded cameras via a scene-light down-mapping LUT (LUT12), or our v1.3 display-light LUT (LUT8). The scene-light conversion was slightly more saturated in the reds, but the other differences were small. With v1.4 that is however no longer the case - the new display-light down-mapping LUTs 8 and 9 are noticeably brighter than the scene-light LUT12. For SDR images of similar brightness, the HDR signal thus needs to be brighter for a scene-light conversion than a display-light conversion.

When shading football, for example, the camera-iris is often adjusted so that the grass pitch sits at around 50% SDR signal:

- Through the display-light v1.4 LUT8 and LUT9, 40% HLG will deliver a 50% SDR output;
- Through the scene-light LUT12, 40% HLG will only deliver a 45 % SDR output,
 - A 45% HLG signal is required to will deliver a 50% SDR output.

The differences in mid-tones arise because of the different HDR and SDR OOTFs. These are now correctly accounted for in the v1.4 release. So an HDR programme, shaded in SDR via the scene-light LUT, may appear slightly-brighter (e.g. grass at 45% HLG rather than 40% HLG) than one shaded via a display-light LUT.

For programme-genres that use a different anchor-point, such as skin-tones or an ice-rink, the differences are less-pronounced. An 80% SDR ice-rink is 65% HLG via the display-light conversion, and 66% HLG via the scene-light. Nonetheless, careful consideration should be given to the choice of down-mapping LUT for camera-shading. As a general rule, the LUT specified for camera-shading should also be used for the primary SDR output. Regardless of which LUT is used it should, to avoid confusion and ensure camera consistency, be identical for all shading-stations in the production gallery - as well as the monitoring-signal used for camera RCP 'touch-downs'.

Extending the SDR Colour Gamut

When using a mix of SDR BT.709 cameras and BT.2100 HLG cameras, significantly-better results can be obtained if (i) the signal-clippers on the SDR cameras are relaxed to EBU Technical Recommendation [R103](#) "preferred" signal levels (-5%/+105%) and (ii) the conversion process takes account of the signals in the sub-blacks² and super-whites. The sub-black and super-white

² signals above below black (BT.709 10-bit code value 64)

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” (or “headroom”) mode, taking account of the black-level offset of the SDR input signals (10-bit code value 64). Because of the improved performance, the scene-light 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 versions, that provide “headroom” for sub-blacks and super-whites. It is therefore important to ensure that the correct LUT hardware-variant is used. See the “Implementation Guidelines for HLG Format Conversion LUTs” for more details.

Licensing Options

Two licences are available. The first is intended for manufacturers wishing to either embed the LUTs within their products, or include the LUTs with their products. The second 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.