

Perceptual Quantiser (PQ) to Hybrid Log-Gamma (HLG) Transcoding

Part of the [HDR-TV](#) series. Last updated June 2017.

Introduction

This document describes the transcode process between PQ and HLG where the display brightness of the PQ and HLG signals are the same. The steps outlined in this document are identical to the procedure described in ITU-R BT.2100-0 [1], ITU-R BT.2390 [2], and a recent conference paper [3], however, more detail has been provided to aid with the transcode process.

Transcoding between PQ and HLG signals is specified in Section 7.1 of ITU-R report BT.2390. When the peak brightness of the HLG and PQ displays are the same, the displayed images from the original and transcoded signals will look identical.

Typically, however, for PQ content the brightness of low-lights and mid-tones remains the same, regardless of the peak brightness of the display. Brighter PQ displays offer increased headroom for specular highlights, but the overall image brightness remains unchanged.

HLG, however, is based on relative brightness. Thus, as the display's peak brightness increases so does the brightness of the entire image. The headroom for specular highlights is a constant number of stops, but the brighter image makes it suitable for viewing in brighter environments.

When, for example, a 4000 cd/m² PQ signal is transcoded to HLG using the method specified in ITU-R BT.2390, it will appear identical on a 4000 cd/m² HLG display, but it may appear darker when shown on a 1000 cd/m² HLG display in brighter environments.

As the PQ and HLG systems have different characteristics, a format conversion rather than a simple transcode is required when the mastering PQ and HLG displays are a very different brightness. Format conversion is described in Section 7.2 of ITU-R report BT.2390.



Transcode PQ to HLG for a Common Display Brightness

System Overview

The transcode process outlined in ITU-R BT.2390 is as follows:

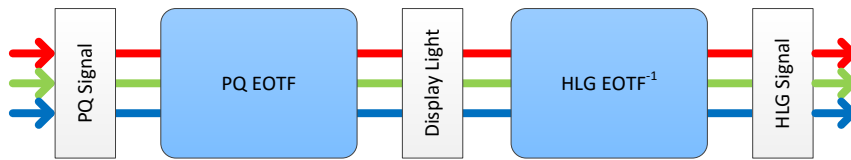


Figure 1: PQ TO HLG High Level Overview

where the HLG EOTF⁻¹ consists of an inverse Opto-Optical Transfer Function (OOTF⁻¹) followed by the HLG OETF:

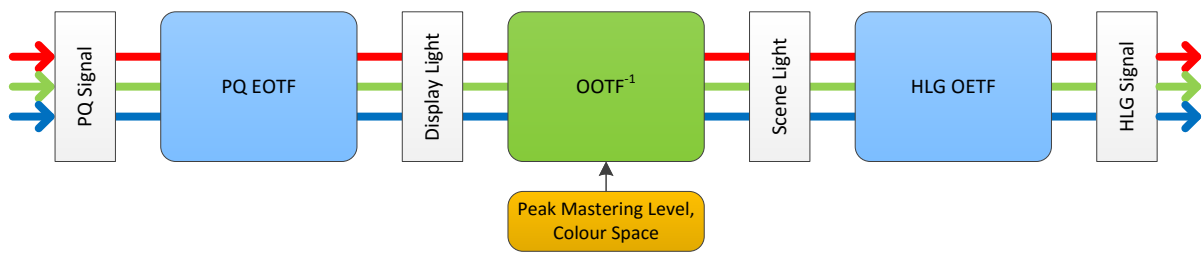


Figure 2: PQ To HLG Overview

The OOTF⁻¹ process can be broken down as follows:

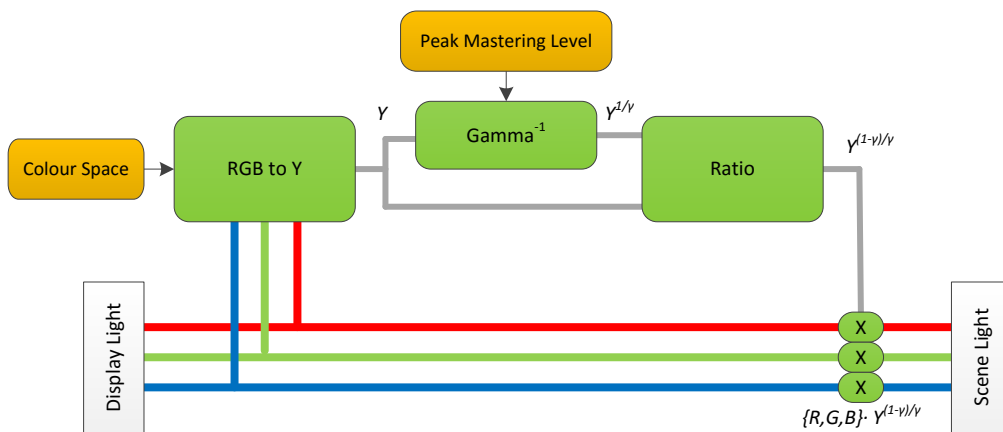


Figure 3: OOTF⁻¹ procedure

The PQ EOTF and HLG OETF are defined by BT.2100-0.

Step by Step Guide

Below is a fully explained procedure for the transcode process. This process is appropriate for implementation in a 3D look up table (LUT). Note, the range of the values at each stage is between 0.0 and 1.0.

1. Apply the PQ EOTF to the signal, as per Table 4 in BT. 2100-0. **Note the multiplication by 10000 is not required.** This is now display light in the range of 0.0 to 1.0, where 1.0 represents 10000 cd/m².

$$Y = \left(\frac{\max\left[\left(E^{1/m_2} - c_1\right), 0\right]}{c_2 - c_3 E^{1/m_2}} \right)^{1/m_1}$$

2. Normalise the display signal using the peak mastering level. The mastering level can be obtained from analysing the signal, or alternatively, may be available as metadata, e.g. by knowing which mastering monitor was used. For a PQ signal graded on a 1000 cd/m² display, there should be no data above 1000 cd/m² as this would have been clipped by the display. Therefore, the signal should be normalised so that 1.0 now corresponds to 1000 cd/m². Similarly, for PQ content graded at 4000 cd/m², there should be no data above 4000 cd/m² as this would have been clipped by the display. Therefore, the signal should be normalised so that 1.0 now corresponds to 4000 cd/m².

$$F_d = \min\left(\left(\frac{Y * 10000}{L_w}\right), 1.0\right)$$

where Y is the $\{R,G,B\}$ signal, and L_w is the peak brightness of mastering display in cd/m². This signal is display referred linear.

3. The OOTF⁻¹ is now applied to convert the display linear signal to a scene linear signal.

First the display luminance of the display is calculated. **Note that the coefficients in the conversion must correspond to the correct colour primaries of the signal.** BT.2020 primaries have been used for the conversion below.

$$Y_d = 0.2627 R_d + 0.6780 G_d + 0.0593 B_d$$



Next the scene luminance is calculated by applying the inverse system gamma.

$$Y_s = (Y_d)^\frac{1}{\gamma}$$

where γ is calculated using the standard formula from BT.2100

$$\gamma = 1.2 + 0.42 \text{Log}_{10}(L_w/1000)$$

Therefore, the linear scene signal R_s , G_s and B_s can be derived as:

$$\begin{aligned} R_s &= R_d \times (Y_d)^\frac{1-\gamma}{\gamma} \\ G_s &= G_d \times (Y_d)^\frac{1-\gamma}{\gamma} \\ B_s &= B_d \times (Y_d)^\frac{1-\gamma}{\gamma} \end{aligned}$$

4. Finally, the HLG OETF is applied to generate the HLG signal. If using the formula from Table 5 in BT.2100-0, please note that the expected input range is [0:12], therefore, the scene linear signals need to be multiplied by 12 before the OETF is applied. Note 5b provides equations for the HLG OETF in the range [0:1], if these equations are used, no such scaling is required.

PQ content graded on a 1000 cd/m² display transcoded to HLG, and then shown on the same screen in the correct HLG ITU-R BT.2100-0 mode (e.g. Sony BVM-X300, “HLG SG Variable(HDR)”) will be identical. The process described above is mathematical and exact (except for small rounding differences). Any other result indicates a mistake in the workflow. The following diagram shows that the processing blocks essentially are cancelled out, resulting in identical displayed light values.

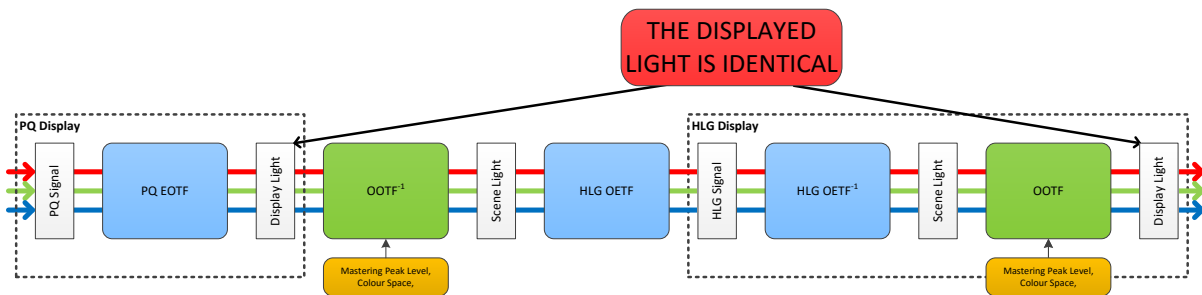


Figure 4: Transparent PQ to HLG Transcode

Transcode HLG to PQ for a Common Display Brightness

System Overview

The transcode process outlined in ITU-R BT.2390 is as follows:

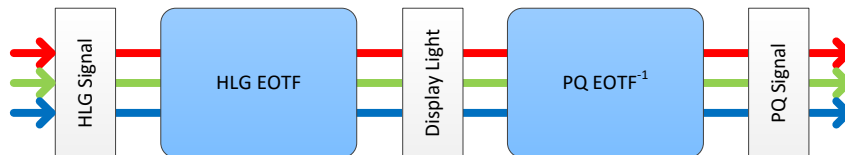


Figure 5: HLG TO PQ High Level Overview

where the HLG EOTF consists of an inverse HLG OETF, followed by the Opto-Optical Transfer Function (OOTF):

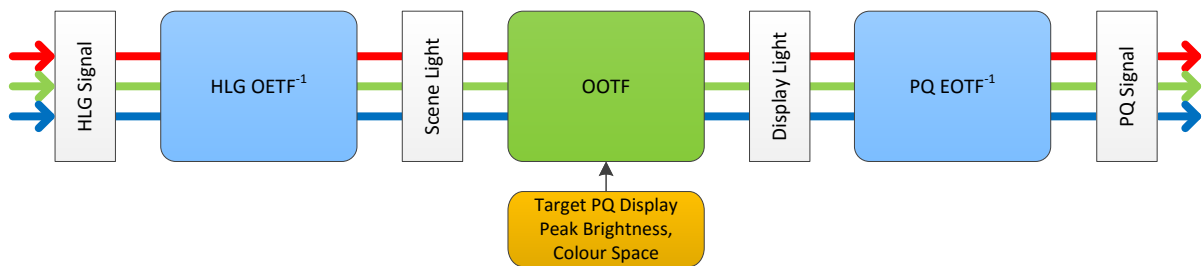


Figure 6: HLG To PQ Overview

The OOTF process can be broken down as follows:

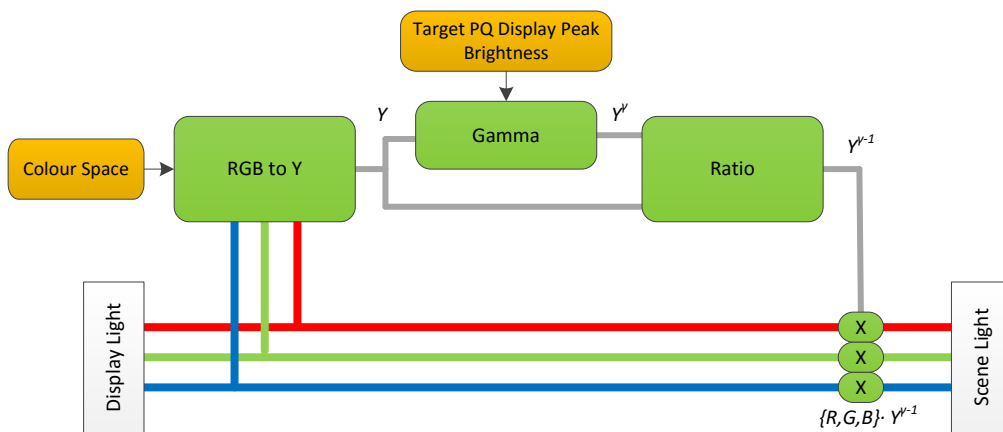


Figure 7: OOTF procedure

The PQ EOTF⁻¹ and HLG OETF⁻¹ are defined by BT.2100-0.

Step by Step Guide

Below is a fully explained procedure for the transcode process. This process is appropriate for implementation in a 3D look up table (LUT). Note, the range of the values at each stage is between 0.0 and 1.0.

1. Apply the HLG OETF⁻¹ to the signal, as per Table 5 in BT. 2100-0. This is now scene light in the range of 0.0 to 12.0.

$$E = \text{OETF}^{-1}[E'] = \begin{cases} 4E'^2 & 0 \leq E' \leq \frac{1}{2} \\ \exp((E' - c)/a) + b & \frac{1}{2} < E' \end{cases}$$

where E is the scene light signal for the components R_s , G_s , and B_s . The values are then scaled by 12 to bring them into the domain [0:1].

Alternatively, the OETF⁻¹ defined in the domain [0:1] (Note 5c) for both input and output can be applied. This does not require the scaling by 12.0.

$$E = \text{OETF}^{-1}[E'] = \begin{cases} E'^2/3 & 0 \leq E' \leq \frac{1}{2} \\ \exp((E' - c)/a) + b & \frac{1}{2} < E' \end{cases}$$

2. Apply the OOTF to turn the scene light into display light, where γ is calculated using the standard formula from BT.2100-0, and L_w is the target PQ display brightness.

$$\gamma = 1.2 + 0.42 \text{Log}_{10}(L_w / 1000)$$

$$F_D = \text{OOTF}[E] = Y_s^{\gamma-1} E$$

$$Y_s = 0.2627 R_s + 0.6780 G_s + 0.0593 B_s$$

$$R_D = Y_s^{\gamma-1} R_s$$

$$G_D = Y_s^{\gamma-1} G_s$$

$$B_D = Y_s^{\gamma-1} B_s$$

3. Normalise the displayed referred signal using the peak mastering level and the PQ peak level of 10000 cd/m².

$$F_D = \min\left(\left(\frac{E_D * L_w}{10000}\right), 1.0\right)$$

Where E_D are the displayed referred R_D , G_D , B_D signals

4. Apply the PQ EOTF⁻¹ as defined in Table 4 of ITU-R BT.2100-0.

$$\text{EOTF}^{-1}[F_D] = \left(\frac{c_1 + c_2 Y^{m_1}}{1 + c_3 Y^{m_1}} \right)^{m_2}$$

where F_D is the display referred signals R_D , G_D , and B_D normalised with the peak mastering level and 10000 cd/m².

HLG content shown on a 1000 cd/m² display and subsequently transcoded to PQ, targeted for the same 1000 cd/m² display, (e.g. Sony BVM-X300) will look identical. The process described above is mathematical and exact (except for small rounding differences). Any other result indicates a mistake in the workflow.

Steps 1 and 2, above, convert the HLG signal to display light values. The display light values represent the final viewed images, irrespective of the choice between HLG and PQ for the signal format, and hence these are the values that need to be preserved. The inverse PQ EOTF applied in step 3 will be exactly inverted by the PQ EOTF in any PQ display. This means that the final displayed light values will be identical for the original HLG signal and the transcoded PQ signal, as shown in the following diagram.

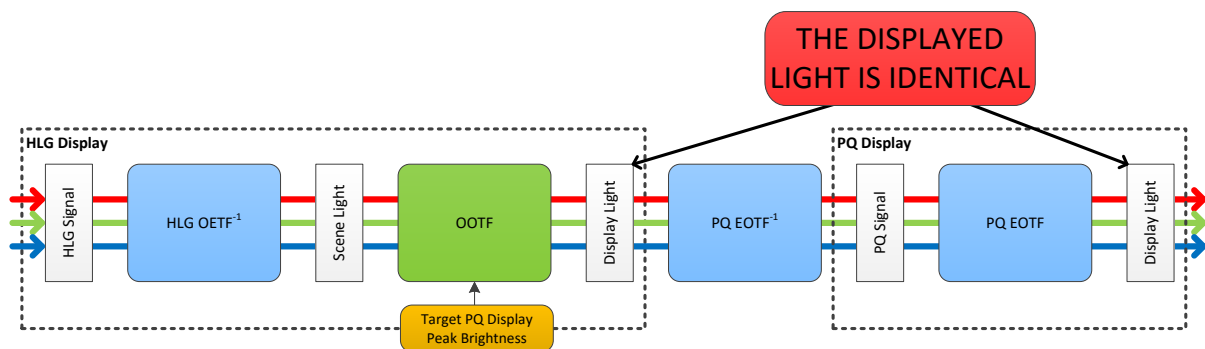


Figure 8: Transparent HLG to PQ Transcode

Implementation of the Transcode Process

The procedures described above can be implemented exactly as described in software. Such an implementation can be found in HDRTools [3], a tool developed by the ITU-T and ISO/IEC community to support video standardisation and compression work.

Alternatively, the procedure can be implemented in a 3D look up table (LUT). 3D LUTs are widely supported in software, such as grading and other post-production tools, as well external SDI/HDMI based devices, however, some care must be taken when using these tools to ensure that the correct conversion are applied as LUTs operate in an RGB colour space while the input and output video is typically YCbCr.

Tools Fully Aware of Wide Colour Gamut

With modern grading, editing and post production tools, the colour space and primaries can be defined based on the production criteria. These can be, for instance, BT.709, DCI.P3 or BT.2020. As the LUT is applied to RGB components, the software must convert the input video to RGB before the LUT can be applied. If the input is YCbCr, the correct YCbCr matrix should be used based on the colour space selected within the project. Similarly, the correct matrix should be used when converting the output of the LUT back to YCbCr from RGB.

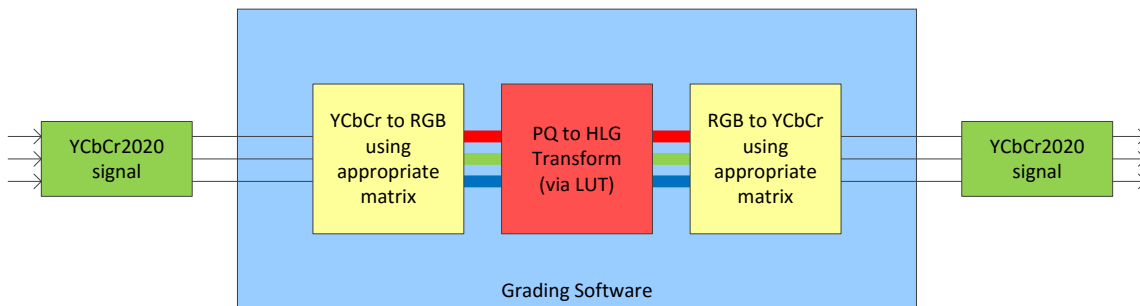


Figure 9: Applying LUT within post-production software

Tools Unaware of Wide Colour Gamut

Some tools, such as external hardware based look up tables, are often not capable of distinguishing between inputs with different colour spaces, and simply assume that all inputs and outputs will be BT.709 colour. This will lead to the incorrect YCbCr to RGB matrix being used, which may result in colour distortion, hue shifts, or clipping. This incorrect matrix operation is illustrated in Figure 10.

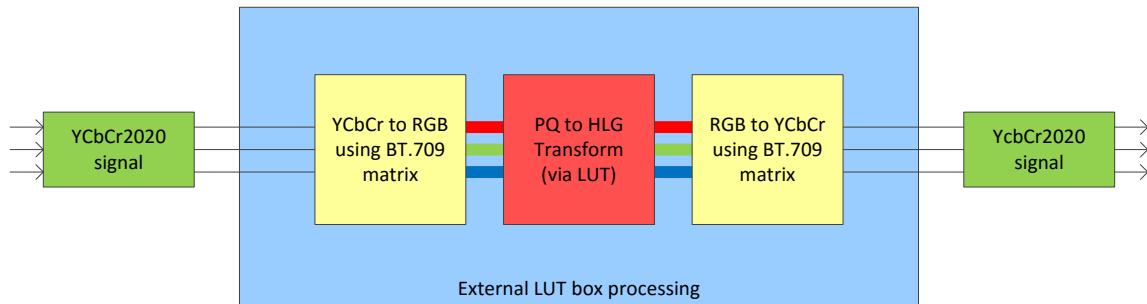


Figure 10: Incorrect LUT conversion with external device which assumes BT.709 YCbCr transform matrix

If the correct matrix cannot be flagged correctly within the LUT processing device, additional matrices can be applied within the LUT itself to compensate for the incorrect matrix. The workflow for such a process is shown below for a BT.2020 input and output.

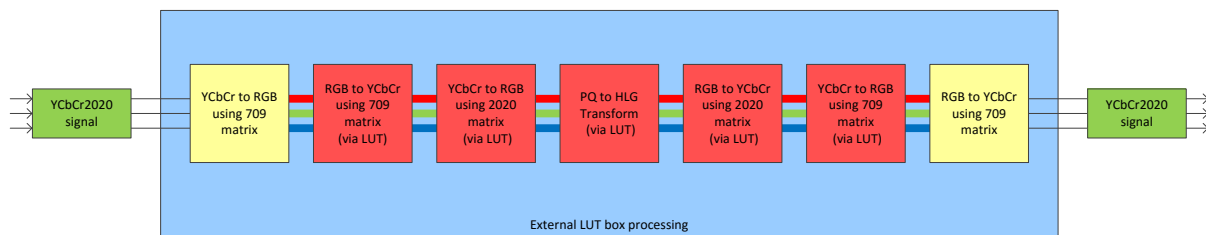


Figure 11: Conversion with external LUT device with YCbCr compensation

The additional conversions (in red, indicated with “via LUT”) aim to reverse the assumed BT.709 conversion to RGB applied by the LUT device and then apply the appropriate conversion matrix for the source material. In the example above, the intended colour space is BT.2020, but the processes can easily be substituted for the appropriate colour space, for example DCI.P3.

References

- [1] ITU-R Recommendation BT. 2100-0, “Image parameter values for high dynamic range television for use in production and international programme exchange”, 2016.
- [2] ITU-R Report BT. 2390-2, “High dynamic range television for production and international programme exchange”, 2017.
- [3] Tim Borer, Andrew Cotton, Manish Pindoria, Simon Thompson, Katy Noland, "Interconversion of High Dynamic Range Video Formats", NAB Conference, Las Vegas, USA, April 2016.
- [4] HDRTTools, <https://gitlab.com/standards/HDRTTools/>, ITU-T, ISO/IEC, 2016.

Version History

Version	Editors	Comments
0.1	MP, TB, AC	Initial Version
0.2	MP, AC, RP	Corrected normalisation step in HLG to PQ conversion

