British Broadcasting Corporation
Research and Development Department

BBC R&D

Conversion of sRGB to HLG

A proposed conversion for use with TTML Subtitles

Date:
April 20, 2017

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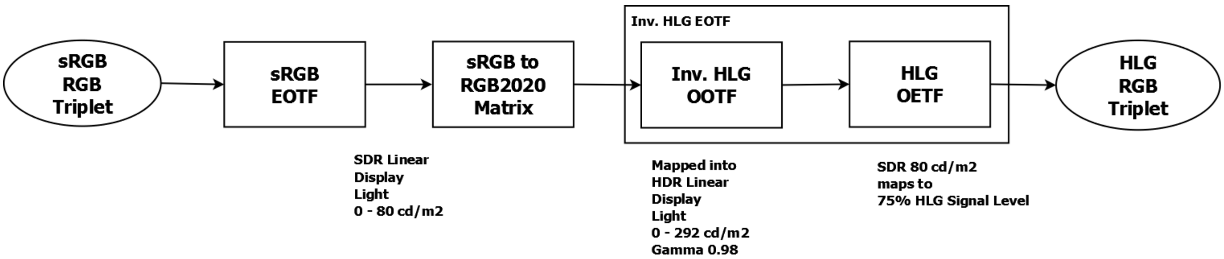
Introduction

This contribution proposes a suggested simple mapping from sRGB values when compositing with Hybrid Log-Gamma (HLG) high dynamic range (HDR) video which is good enough for all but the most critical applications. It is suitable for implementation in software renderers and could be used for generating a look up table. The mapping ensures that 100% sRGB signal maps to the 75% HLG reference level for graphics white.



sRGB EOTF

sRGB is an output-referred RGB colour space[1] which has the same colour primaries but different transfer function as ITU-R BT.709.

The sRGB EOTF is formally given as:

$$C_{\text{sRGB}} = \begin{cases} \frac{C'_{\text{sRGB}}}{12.92} & C'_{\text{sRGB}} \leqslant 0.04045 \\ \left(\frac{C'_{\text{sRGB}}+0.055}{1.055}\right)^{2.4} & C'_{\text{sRGB}} > 0.04045 \end{cases} \tag{1}$$

Where C' is the non-linear R, G or B component in the range 0 to 1 and C is the normalised, linear display light R, G or B component in the range 0 to 1.

However this can be approximated as:

$$C_{\text{sRGB}} = \left(C'_{\text{sRGB}}\right)^{2.2} \tag{2}$$

sRGB to ITU-R BT.2020 RGB Matrix

Firstly, the linearised sRGB signal is converted to XYZ.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R_{\text{sRGB}} \\ G_{\text{sRGB}} \\ B_{\text{sRGB}} \end{bmatrix} \tag{3}$$

[1] Peres, M.R. (Ed.), "The Focal Encyclopedia of Photography" Focal Press, Burlington, MA, 2013 pp. 397-398

Secondly, the XYZ signal is converted to linearised RGB with ITU-R BT.2020 Primaries.

$$\begin{bmatrix} R_{2020} \\ G_{2020} \\ B_{2020} \end{bmatrix} = \begin{bmatrix} 1.7167 & -0.3557 & -0.2534 \\ -0.6667 & 1.6165 & 0.0158 \\ 0.0176 & -0.04277 & 0.9421 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{4}$$

Inverse HLG OOTF

To directly map an sRGB signal in the range into an HLG signal, an HLG screen peak brightness can be chosen such that the sRGB signal peak is directly mapped to a certain percentage of the HLG signal level. In this case, we want the sRGB 100% peak signal to be mapped to 75% HLG signal level, this requires an HLG EOTF with 292 cd/m^2 peak brightness.

The inverse OOTF for a 292 cd/m^2 HLG image is:

$$Y = Y^{\text{`}\frac{1}{0.98}} \tag{5}$$

As this change is very small, it can be ignored.

As there is no gamma adjustment required, the conversion process can therefore be simplified using normalised signals and a scaling function. The scaling function SF is calculated:

$$SF = \frac{e^{\frac{0.75-c}{a}} + b}{12} \tag{6}$$

Where $a = 0.17883277$, $b = 1 - 4a$ and $c = 0.5 - a\ln(4a)^{5b}$. Resulting in a SF of 0.265.

A scaling function of 0.265 ensures that 100% sRGB delivers 75% HLG signal. Equation 5 can therefore be replaced by:

$$\hat{C}_{2020} = 0.265 \times C_{2020} \tag{7}$$

Where C is the linear R, G or B component in the range 0 to 1 and $\hat{C}$ is the scaled, linear component R, G or B component in the range 0 to SF.

HLG OETF

$$C^{\text{`}}_{\text{HLG}} = \begin{cases} \sqrt{3 \times \hat{C}_{2020}} & 0.0 \leqslant \hat{C}_{2020} \leqslant 1.0/12.0 \\ a \times ln(12 \times \hat{C}_{2020} - b) + c & \hat{C}_{2020} > 1.0/12.0 \end{cases} \tag{8}$$

Where $C^{\text{`}}$ is the non-linear R, G or B component in the range 0 to 1 and $\hat{C}$ is the scaled, linear display light R, G or B component in the range 0 to SF, $a = 0.17883277$, $b = 1 - 4a$ and $c = 0.5 - a\ln(4a)^{5b}$.

Suggested update to W3C Timed Text Markup Language 2 Appendix P

This document is available online[2]. This update changes Appendix P to present methods for converting sRGB to both HDR methods presented in ITU-R BT.2100[3].

The new text appears on the following page.

[2] `https://w3c.github.io/ttml2/spec/ttml2.html#hdr-compositing`

[3] ITU-R BT.2100-1 (pre-publication), “Image parameter values for high dynamic range television for use in production and international programme exchange”, ITU, Geneva, 2017.

Hybrid Log-Gamma

The following illustrates compositing of sRGB pixels onto Hybrid Log-Gamma (HLG) HDR pixels.

1. Let (r,g,b) be a full-range 8-bit sRGB pixel with opacity of A between 0 and 255.
2. Let (R,G,B) and (R_c,G_c,B_c) be narrow-range 10-bit pixels in the system colorimetry specified in [ITU BT.2100-1] using HLG EOTF and narrow-range quantization. Subscript $_c$ denoting the video signal post-compositing.
3. Let (X,Y,Z) be pixels in the system colorimetry specified in CIE 1931 XYZ colour space.
4. Invert the 8-bit full-range quantization:
   $(r,g,b)/255 \rightarrow (r,g,b)$
   $A/255 \rightarrow A$
5. Linearize using the sRGB EOTF:
   $(r^{2.2},g^{2.2},b^{2.2}) \rightarrow (r,g,b)$
6. Convert from sRGB color space to [ITU BT.2100-1] color space:
   $[(0.4124,0.3576,0.1805),$
   $(0.2126,0.7152,0.0722),$
   $(0.0193,0.1192,0.9505)] \bullet (r,g,b) \rightarrow (X,Y,Z)$
   $[(1.7167,-0.3557,-0.2534),$
   $(-0.6667,1.6165,0.0158),$
   $(0.0176,-0.04277,0.9421)] \bullet (X,Y,Z) \rightarrow (r,g,b)$
7. Apply simplified inverse HLG OOTF:
   $((0.265r),(0.265g),(0.265b)) \rightarrow (r,g,b)$
8. Apply HLG OETF specified in [ITU BT.2100-1]:
   $(HLG(r),HLG(g),HLG(b)) \rightarrow (r,g,b)$
   where $HLG(x) = (3x)^{0.5}$ if $0 \leqslant x \leqslant 1/12$ or $HLG(x) = a \bullet \ln(12x-b)+c$ if $x > 1/12$
   and $a = 0.17883277$ and $b = 1-4a$ and $c = 0.5 - a\ln(4a)^{5b}$
9. Apply 10-bit narrow-range quantization:
   $(Q(r),Q(g),Q(b)) \rightarrow (r,g,b)$
   where $Q(x) = floor((940-64) \bullet x + 64.5)$
10. Composite foreground graphic (r,g,b) over background video (R,G,B) with opacity A to yield (R_c,G_c,B_c):
    $((A \bullet r + (1-A)R),(A \bullet g + (1-A)G),(A \bullet b + (1-A)B)) \rightarrow (R_c,G_c,B_c)$
11. Clamp output to 10-bit signal range:
    $(\text{clamp}(R_c),\text{clamp}(G_c),\text{clamp}(B_c)) \rightarrow (R_c,G_c,B_c)$
    where $\text{clamp}(x) = x$ if $0 \leqslant x \leqslant 1023$ or 0 if $x < 0$ or 1023 if $x > 1023$