SMPTE ST 2094-20:2016

SMPTE STANDARD

Dynamic Metadata for Color Volume Transform — Application #2

Table of Contents

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Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

The color volume transform Application #2 uses content-dependent dynamic metadata to reproduce the artistic intent of High Dynamic Range and Wide Color Gamut content as accurately as possible on displays having a smaller color volume than that of the display with which that content was mastered.

This dynamic metadata is typically generated in a trim pass, either starting from automatically-generated dynamic metadata or from automatically-derived dynamic metadata using a numerical optimization process when both an HDR and an SDR image are available.

A colorist could add corrections to the transform, typically on a scene by scene basis but also on an image by image basis if desired. The transform is captured in parameters. The parameters consist of: a group that defines a region-based tone mapping curve that operates on image data in a perceptually-uniform domain; a fine-tuning adjustment to the region-based tone mapping curve; and parameters that specify luminance-dependent color saturation correction.

In some cases, it could be desirable to limit the number of parameters used. This could be the case, for example, in a live broadcast scenario. Typically, only one or two of the parameters that define the region-based tone mapping curve will be used. These parameters could be set by an operator, or could be automatically generated on the basis of a scene analysis.

1 Scope

This standard specifies the content-dependent Color Volume Transform metadata set for Application #2, a specialized model of the color volume transform defined by the core components document SMPTE ST 2094-1.

The Color Volume Transform is based on a tone mapping curve that operates on image data in a perceptually-uniform domain and a luminance-dependent saturation gain curve. Both the tone mapping curve and the saturation gain curve are fully characterized by a set of parameters.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:"

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: Normative prose shall be the authoritative definition; Tables shall be next; then formal languages; then figures; and then any other language forms.

3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this engineering document. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this engineering document are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

SMPTE ST 2086:2014, Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images

SMPTE ST 2094-1:2016, Dynamic Metadata for Color Volume Transform — Core Components

ISO 11664-1:2007(E) / CIE S 014-1/E:2006, Colorimetry — Part 1: CIE Standard Colorimetric Observers

ISO 11664-3:2012(E) / CIE S 014-3/E:2011, Colorimetry — Part 3: CIE Tristimulus Values

ISO 11664-5:2009(E), Colorimetry — Part 5: CIE 1976 L*u*v* Colour Space and *u′*, *v′* Uniform Chromaticity Scale Diagram

4 Terms and Definitions

For the purposes of this document, the terms and definitions given in SMPTE ST 2094-1 and the following apply.

4.1 input image essence

image essence to which the color volume transform is applied and having three color components labeled R, G and B, where the R component corresponds to the Mastering Display Color Volume Display Primary with the largest x chromaticity coordinate, the G component corresponds to the Mastering Display Color Volume Display Primary with the largest y chromaticity coordinate, and the B component corresponds to the remaining Mastering Display Color Volume Display Primary

4.2 *u’v’* chromaticity coordinates

chromaticity coordinates *u’* and *v’* in the CIE 1976 *u’*, *v’* uniform chromaticity scale diagram, as specified in ISO 11664-5

4.3 Y*u’v’* color space

color space with coordinates Y, *u′*, *v′*, where Y is the Y component of the CIE 1931 standard colorimetric system defined in ISO 11664-1, and *u′*, *v′* are CIE 1976 chromaticity coordinates as defined in ISO 11664-5.

5 Application Identification

The **ApplicationIdentifier** value shall be 2 and the **ApplicationVersion** value shall be 0.

These two values identify this document as the defining document for the metadata set specified in Section 8.1.

6 Extension of the Processing Window

6.1 Selection of Pixels for Processing

The extended processing window shall be the intersection of the **ProcessingWindow** as defined in SMPTE ST 2094-1 and a pixel selector. The pixel selector shall be a color volume in the Y*u’v’* color space defined by the luminance range of Section 6.2 and the chromaticity area of Section 6.3.

Zero or more extended processing windows shall be defined. Each extended processing window shall be associated with a set of metadata as defined in Section 7.

6.2 Luminance Range Specification

6.2.1 Luminance Lower Bound

The **LuminanceLowerBound** shall be in the range [0, 4095] and in multiples of 1. The luminance lower value [cd/m^2] is calculated according to:

$$\text{Luminance Lower Value} = 10^{(\textbf{LuminanceLowerBound}/1000)} - 1 \qquad (1)$$

6.2.2 Luminance Upper Bound

The **LuminanceUpperBound** shall be in the range [0, 4095] and in multiples of 1. The value shall be no less than the **LuminanceLowerBound**. The luminance upper value [cd/m^2] is calculated according to:

$$\text{Luminance Upper Value} = 10^{(\textbf{LuminanceUpperBound}/1000)} - 1 \qquad (2)$$

6.2.3 Luminance Range Selector

The **LuminanceRangeSelector** shall be true to specify that the Luminance Range is the closed range from Luminance Lower Bound to Luminance Upper Bound (including the bounds). The Luminance Range Selector shall be false to specify that the Luminance Range is the union of the open ranges below Luminance Lower Bound and above Luminance Upper Bound (excluding the bounds).

6.3 Chromaticity Area Specification

6.3.1 Chromaticity Disk Center

The Chromaticity Disk shall be a disk in the *u’v’* chromaticity plane.

The **ChromaticityDiskCenter** shall specify the center of the Chromaticity Disk. The value shall be a *u’v’* chromaticity coordinate. The *u’* and *v’* value shall be in the range [0, 1023/1632] and in multiples of 1/1632.

6.3.2 Chromaticity Disk Radius

The **ChromaticityDiskRadius** shall be the radius of the Chromaticity Disk. The value shall be in the range [0, 1023/1632] and in multiples of 1/1632.

6.3.3 Chromaticity Area Selector

The **ChromaticityAreaSelector** shall be true to specify that the Chromaticity Area is the closed extent of the Chromaticity Disk. The Chromaticity Area Selector shall be false to specify that the Chromaticity Area is the open area outside the Chromaticity Disk.

7 Color Volume Transform

7.1 Saturation Gain Function

The **SaturationGainFunction** shall be a sampled function as defined in SMPTE ST 2094-1. It maps a luminance based input value to a saturation scaling factor.

The first pair ({ x_0, y_0 }, where x_0 = 0) may be omitted, in which case the first pair shall have the default value { 0.0, 0.0 }.

The last pair ({ x_z, y_z }, where x_z = 1 and z+1 being the length of the list) may be omitted, in which case this last pair shall have the default value { 1.0, 1.0 }.

This sampled function shall have no more than 6 pairs, excluding omitted pairs.

The x_i and y_i values of the sampled function shall be multiples of 1/255.

Before interpolation, the list of xy pairs shall be converted to a list of pq pairs, where:

$$\{ p_i, q_i\} = 2^{-15*\{ x_i, y_i \}} \tag{3}$$

The list of pq pairs shall be appended with a pair { 0.0, 0.0 }.

The $y = f(x)$ values shall be obtained through interpolation. The interpolation shall be linear interpolation.

The processing of $y = f(x)$ is:

$$y = q[i] + (q[i-1] - q[i]) \times \frac{x - p[i]}{(p[i-1] - p[i])} \tag{4}$$

where:

y = output value

x = input value

$q[i]$ = element q_i in the list

$p[i]$ = element p_i in the list

i = index into the list, such that $p[i] \leq x < p[i-1]$

7.2 Tone Mapping Input Signal Weights

The **ToneMappingInputSignalWeights** shall be a vector with four elements. They determine the relative weights of the color components R, G, B, of the input image essence and luminance value Y for use in the Region-Based Tone Mapping. The elements each shall be in the range [0,1] and in multiples of 1/255.

The order of the elements shall be R, G, B, Y.

At least one element of the vector shall have a value of 1.0.

7.3 Local Slope Adjustments

7.3.1 Introduction

The Local Slope Adjustments allows for localized slope adjustments on the Tone Mapping Curve.

7.3.2 Tone Mapping Input Signal Black Level Offset

The **ToneMappingInputSignalBlackLevelOffset** shall be a number in the range [0,1] and in multiples of 1/255. It is subtracted from the signal and used to calculate the gain of the signal as a first step in the Tone Mapping process.

7.3.3 Tone Mapping Input Signal White Level Offset

The **ToneMappingInputSignalWhiteLevelOffset** shall be a number in the range [0,1] and in multiples of 1/255. It is used to calculate the gain of the signal as a second step in the Tone Mapping process.

7.3.4 Shadow Gain Control

The **ShadowGainControl** shall be a number in the range [0,2] and in multiples of 2/255. It is used to adjust the steepness of the Region-Based Tone Mapping curve in its shadow (darker) region.

7.3.5 Highlight Gain Control

The **HighlightGainControl** shall be a number in the range [0,2] and in multiples of 2/255. It is used to adjust the steepness of the Region-Based Tone Mapping curve in its highlight (brighter) region.

7.3.6 Mid-Tone Width Adjustment Factor

The **MidToneWidthAdjustmentFactor** shall be a number in the range [0,2] and in multiples of 2/255. It is used to adjust the width of the mid-tone region of the Region-Based Tone Mapping curve.

7.3.7 Tone Mapping Output Fine Tuning Function

The **ToneMappingOutputFineTuningFunction** shall be a sampled function as defined in ST 2094-1. It maps a local tone mapping input value to an adjusted value. The first pair shall be { 0.0, 0.0 } and last pair shall be { 1.0, 1.0 }.

The first pair ({ x_0, y_0 }, where x_0 = 0) may be omitted, in which case the first pair shall have the default value { 0.0, 0.0 }.

The last pair ({ x_z, y_z }, where x_z = 1 and $z+1$ being the length of the list) may be omitted, in which case this last pair shall have the default value { 1.0, 1.0 }.

This sampled function shall have no more than 10 pairs, excluding omitted pairs.

The x_i and y_i values of the sampled function shall be multiples of 1/255.

8 Application Constraints

8.1 Metadata Set

A metadata set shall contain exactly one of each of the following:

- **ApplicationIdentifier** (2)
- **ApplicationVersion** (0)
- **TimeInterval**
    - metadata items as defined in SMPTE ST 2094-1:
      TimeIntervalStart and
      TimeIntervalDuration
- **ProcessingWindow**
- **TargetedSystemDisplay**
    - Targeted System metadata items as defined in SMPTE ST 2094-1:
      TargetedSystemDisplayPrimaries
      TargetedSystemDisplayWhitePointChromaticity
      TargetedSystemDisplayMaximumLuminance and
      TargetedSystemDisplayMinimumLuminance
- **ColorVolumeTransform**
    - **SaturationGainFunction**
    - **ToneMappingInputSignalWeights**
    - Local Slope Adjustments
        - **ToneMappingInputSignalBlackLevelOffset**
        - **ToneMappingInputSignalWhiteLevelOffset**
        - **ShadowGainControl**
        - **HighlightGainControl**
        - **MidToneWidthAdjustmentFactor**
        - **ToneMappingOutputFineTuningFunction**

The **ProcessingWindow** comprises the following items which shall be all omitted or exactly one of each of the following metadata items shall be provided:

- metadata items as defined in SMPTE ST 2094-1:
  UpperLeftCorner
  LowerRightCorner
  WindowNumber
- metadata items defined in this document:
  Luminance Range Specification
    - **LuminanceLowerBound**
    - **LuminanceUpperBound**
    - **LuminanceRangeSelector**

  Chromaticity Area Specification
    - **ChromaticityDiskCenter**
    - **ChromaticityDiskRadius**
    - **ChromaticityAreaSelector**

8.2 Processing Window Constraints

When all items of the **ProcessingWindow** are omitted, the **ProcessingWindow** as well as the extended processing window shall contain all pixels in the image.

If multiple metadata sets are defined for the same pixel of an image and with the same **TargetedSystemDisplay** metadata values, the set with the highest **WindowNumber** shall define the color volume transform associated with the pixel.

Annex A Mapping of Application #2 to the Generalized Color Volume Transform Model (Informative)

The diagram in Figure A.1 describes Application #2 in the framework of the Generalized Color Volume Transform Model presented in SMPTE ST 2094-1, Annex A. The process blocks applied are the Gamut Shaping and Tone Mapping.

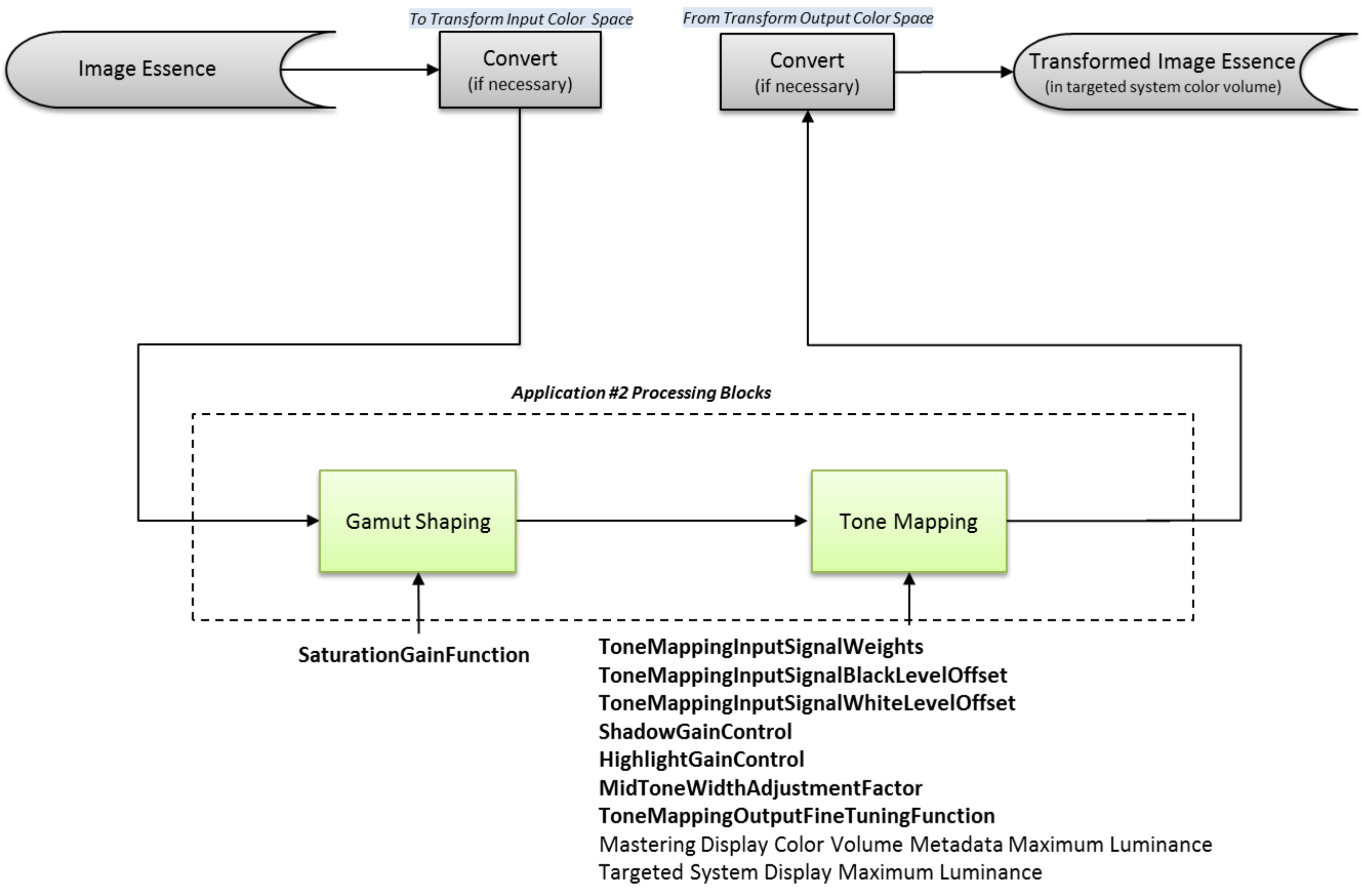


Figure A.1 – Application 2 mapped on generalized model

Annex B Dynamic Range Transform Method Description (Informative)

B.1 Introduction

This section describes a detailed calculation using the metadata as described in this specification.

The calculation as presented in Annex B is valid for input image essence components coded as three primary additive R, G, B. The input image essence R, G, B components need to be in linear light, normalized to the Maximum Display Mastering Luminance in the range [0,1] and in the mastering display color volume (SMPTE ST 2086). The output signals are normalized linear light (R, G, B) image essence components, adapted for the targeted system display color volume.

B.2 Extension of the Processing Window

The usage of an extended processing window provides the colorist with additional freedom to create an alternate set of tone mapping parameters for a selected object by means of such extended processing window. SMPTE ST 2094-1 can define a **ProcessingWindow** and no pixels outside of this window are affected by the alternate set of metadata. The pixels to be modified are further selected by a pixel selector, being a color volume that is defined by a luminance range (Section 6.2) and a chromaticity area (Section 6.3).

The values of *u'*, *v'*, and Y are needed by the pixel selector. These values can be calculated as shown in the example contained in equations (5) to (7). In this example, the input signal is encoded with ITU-R BT.2020 color encoding primaries:

$$\begin{pmatrix} \mathrm{X} \\ \mathrm{Y} \\ \mathrm{Z} \end{pmatrix} = \begin{pmatrix} 0.6370 & 0.1446 & 0.1689 \\ 0.2627 & 0.6780 & 0.0593 \\ 0.0000 & 0.0281 & 1.0610 \end{pmatrix} \times \begin{pmatrix} \mathrm{R}_{2020} \\ \mathrm{G}_{2020} \\ \mathrm{B}_{2020} \end{pmatrix} \qquad (5)$$

u' and *v'* follow from:

$$u' = \frac{4X}{X + 15Y + 3Z} \qquad (6)$$

and

$$v' = \frac{9Y}{X + 15Y + 3Z} \qquad (7)$$

The pixel selector forms a cylinder in Y*u'v'* space as depicted in Figure B.1.

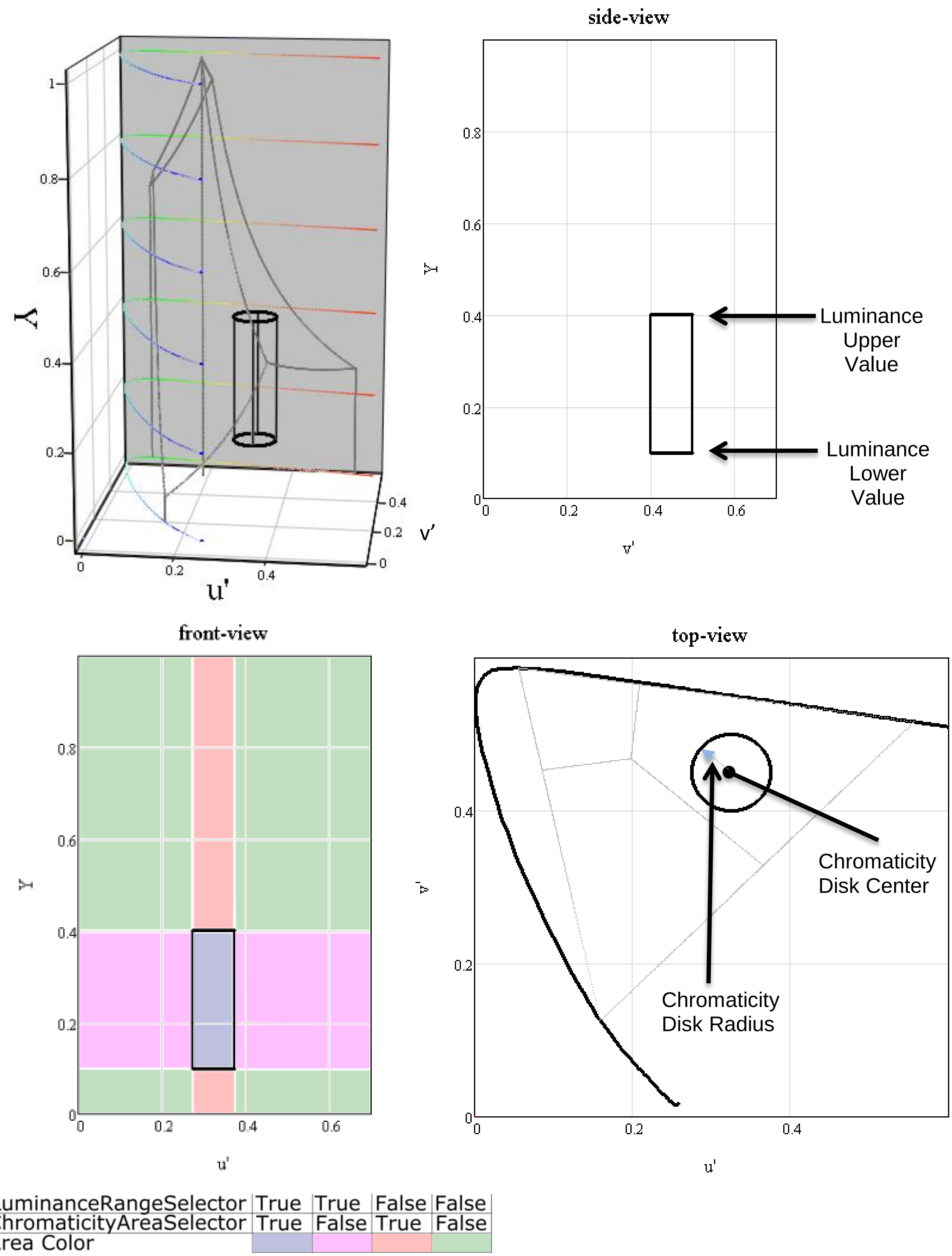


Figure B.1 – Pixel Selector

B.3 Gamut Shaping

Input to the Gamut Shaping process are the three pixel components R_{HDR}, G_{HDR}, B_{HDR}. Output of this process are three saturation-compensated pixel components R_{HDR_S}, G_{HDR_S}, B_{HDR_S}.

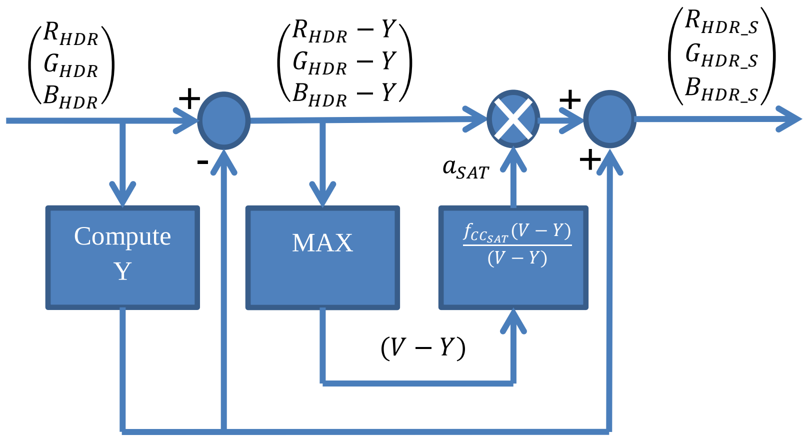


Figure B.2 – Gamut Shaping process

The pixel components R_{HDR_S}, G_{HDR_S}, B_{HDR_S} are calculated according to:

$$\begin{pmatrix} R_{HDR\_S} \\ G_{HDR\_S} \\ B_{HDR\_S} \end{pmatrix} = a_{SAT} \times \begin{pmatrix} R_{HDR} - Y \\ G_{HDR} - Y \\ B_{HDR} - Y \end{pmatrix} + \begin{pmatrix} Y \\ Y \\ Y \end{pmatrix} \tag{8}$$

where:

$$Y = c_1 \times R_{HDR} + c_2 \times G_{HDR} + c_3 \times B_{HDR} \tag{9}$$

with c_n, n=1,2,3, being the luminance coefficients according to the mastering display primaries and white point. See ITU-R BT.2020 for the reference primaries and calculation of Y from R, G, B. By way of example, in case the mastering display primaries and white point are that of ITU-R BT.2020: $c_1 = 0.2627$, $c_2 = 0.6780$, and $c_3 = 0.0593$.

$(V - Y)$ Is calculated according to

$$(V - Y) = \max(R_{HDR} - Y, G_{HDR} - Y, B_{HDR} - Y) \tag{10}$$

a_{SAT} represents the relative desaturation strength, depending on color saturation and luminance. When converting to a smaller color volume, pure saturated primaries with high intensity cannot be attained anymore. The $(V - Y)$ signal excursion is highest on the point where this will happen strongest.

$$a_{SAT} = \begin{cases} 1, & (V - Y) = 0 \\ \dfrac{f_{CC_{SAT}}(V - Y)}{(V - Y)}, & otherwise \end{cases} \tag{11}$$

The $f_{cc_{sat}}$ is the sampled function **SaturationGainFunction** as defined in Section 7.1. The curve settings define the amount of desaturation wanted in order to prevent hue shifts due to clipping.

B.4 Tone Mapping Process

Input to the Tone mapping process are the pixel components R_{HDR_S}, G_{HDR_S}, B_{HDR_S}. Output of this process are the pixel components R_{SDR}, G_{SDR}, B_{SDR}.

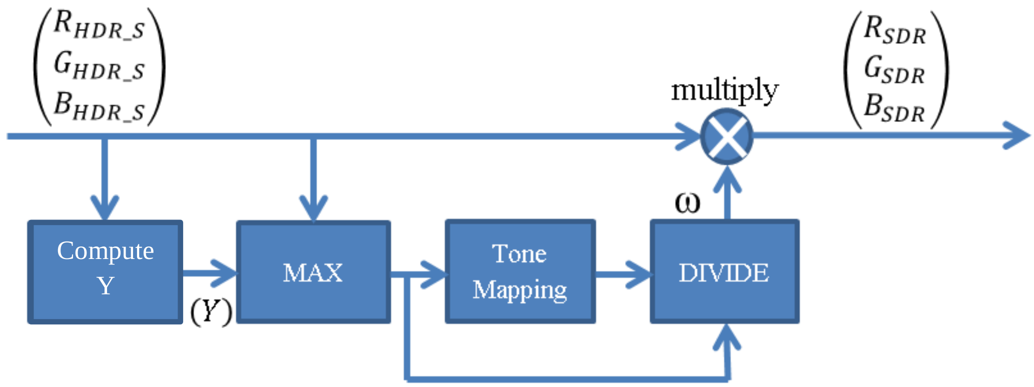


Figure B.3 – Tone Mapping process

Compute Y

$$Y = c_1 \times R_{HDR\_S} + c_2 \times G_{HDR\_S} + c_3 \times B_{HDR\_S} \quad (12)$$

with c_n, n=1,2,3, being the luminance coefficients according to the mastering display primaries and white point. See ITU-R BT.2020 for the reference primaries and calculation of Y from R, G, B. By way of example, in case the mastering display primaries and white point are that of ITU-R BT.2020: $c_1 = 0.2627$, $c_2 = 0.6780$, and $c_3 = 0.0593$.

Maximum signal process

Input to the Maximum signal process are the pixel components R_{HDR_S}, G_{HDR_S}, B_{HDR_S} and Y. Output of this process is a_{RGBY} representing the maximum value. a_{RGBY} Is calculated according to:

$$a_{RGBY} = \max\left(\alpha R_{HDR\_S}, \beta G_{HDR\_S}, \gamma B_{HDR\_S}, \delta Y\right) \quad (13)$$

where $(\alpha, \beta, \gamma, \delta)$ represent the tone mapping weights (**ToneMappingInputSignalWeights**). Tone mapping weights determine the relative weights of the R, G, B, and Y components in tone mapping. Input value to the tone mapping function is a_{RGBY}. The highest weight allowed is 1.

Image essence data process

Figure B.4 is a detailed representation of the block "Tone Mapping" in Figure B.3. It shows the HDR data generation process for an input video signal that is converted into a SDR video signal.

The input signal is first converted to the perceptually-uniform domain based on the Mastering Display Maximum Luminance. In this domain, after black and white stretching, it is processed by the tone mapping curve, which in itself is controlled by the **HighlightGainControl**; **ShadowGainControl** and **MidToneWidthAdjustmentFactor**. Next the Tone Mapping Output Signal Offset Function is applied and the signal is converted back to the linear light domain based on the maximum luminance of the Targeted System Display Maximum Luminance. Finally the ratio of the output and the input of this chain is determined, resulting in the scaling factor ω as shown in Figure B.3.

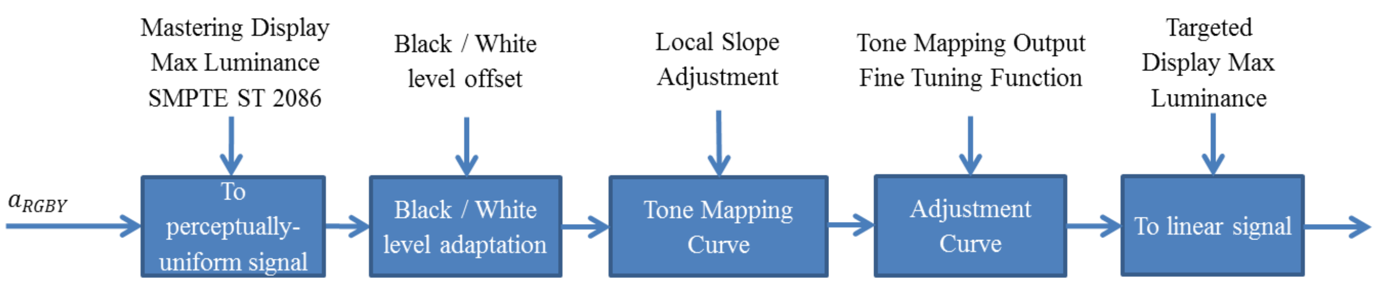


Figure B.4 – HDR data generator for HDR to SDR video

The first block ("To perceptually-uniform signal") is intended to create a perceptually-uniform component. The perceptually-uniform signal is obtained using equation (14):

$$v(x, L) = \frac{\log_{10}\left(1 + (\rho(L) - 1) \times x^{\frac{1}{2.4}}\right)}{\log_{10}(\rho(L))} \quad (14)$$

where:

$$\rho(L) = 1 + (33 - 1) \times \left(\frac{L}{10000}\right)^{\frac{1}{2.4}} \quad (15)$$

The input parameter x in equation (14) is the a_{RGBY} component, and v is the perceptually-uniform color component, when applied to the linear components normalized to 0…1, where 1 corresponds to the peak luminance.

$$a_{PUS} = v(a_{RGBY}, L_{source})$$

where: (16)

L_{source} = Maximum Display Mastering Luminance

Figure B.5 depicts an example for 5000 cd/m^2.

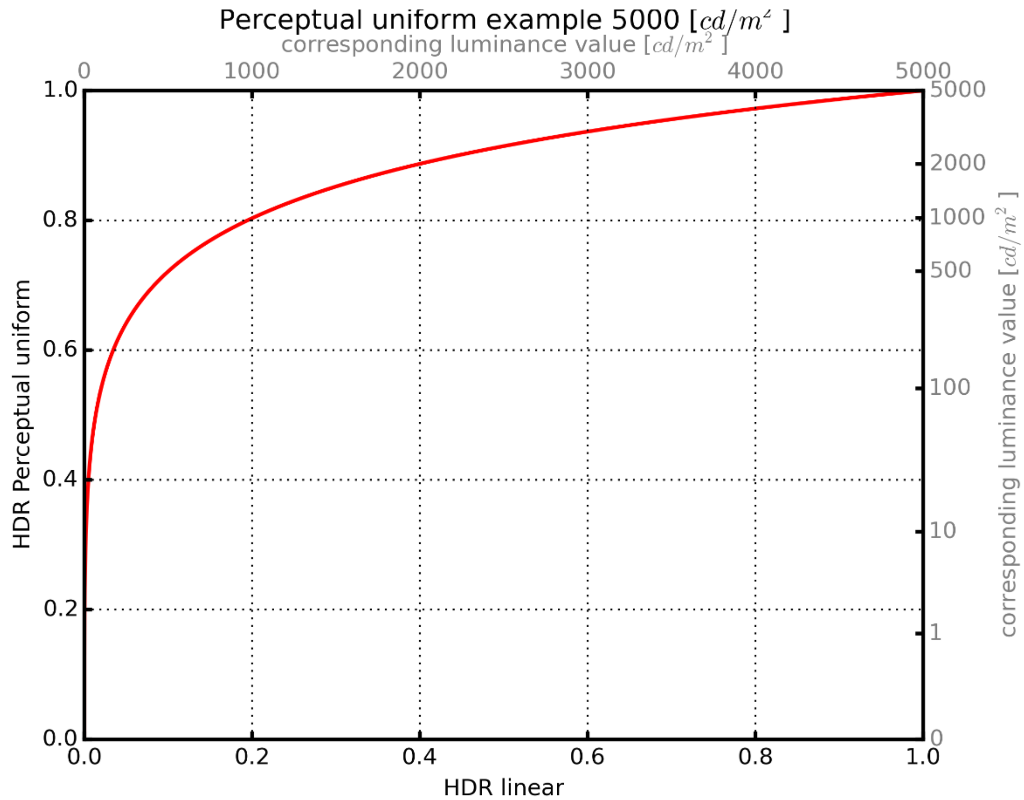


Figure B.5 – example curve for L = 5000 cd/m²

a_{PUS} Is adapted by the black and white level offset to compute a_{BW}. An example of black and white level offset is depicted in Figure B.6.

$$a_{BW} = \frac{a_{PUS} - blo}{1 - wlo - blo}$$

where:

$$wlo = \frac{255 \times \mathbf{ToneMappingInputSignalWhiteLevelOffset}}{510} \quad (17)$$

$$blo = \frac{255 \times \mathbf{ToneMappingInputSignalBlackLevelOffset}}{2040}$$

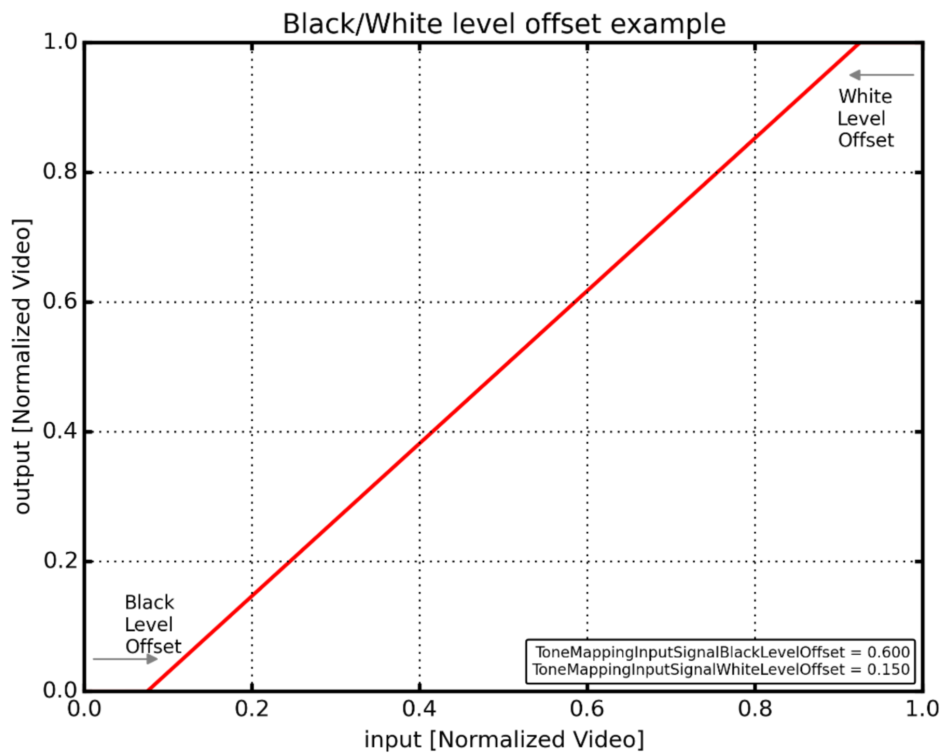


Figure B.6 – Example curve for black and white level offset

Subsequently the Tone Mapping curve is applied. The basics of the curve are explained below and graphically shown in Figure B.7.

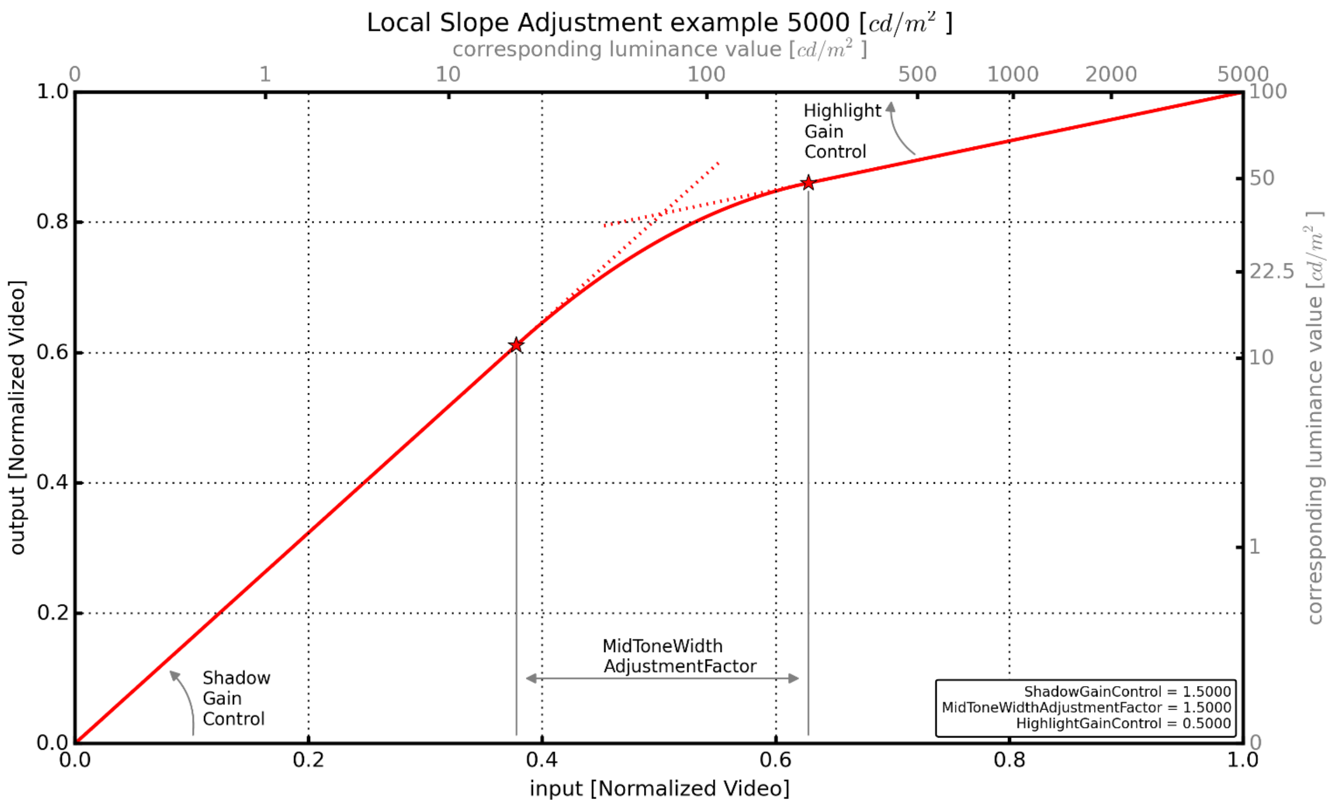


Figure B.7 – Tone mapping curve shape

The tone mapping curve is applied in a perceptually-uniform domain and is a piece-wise curve constructed out of three parts:

- The bottom section is linear, and its steepness is determined by the **ShadowGainControl**.
- The upper section is also linear, and its steepness is determined by the **HighlightGainControl**.
- The mid-section is a parabola providing a smooth bridge between the two linear sections. The width of the cross-over is determined by the **MidToneWidthAdjustmentFactor**.

Equation (18) up to and including equation (29) give an overview of the calculations in order to arrive at the piece-wise constructed curve.

Note that these calculations are valid under the condition that $L_{source} > L_{target}$.

$$TMO(x) = \begin{cases} SGC \times x, & 0 \le x \le x_{SGC} \\ ax^2 + bx + c, & x_{SGC} < x < x_{HGC} \\ HGC \times x + 1 - HGC, & x_{HGC} \le x \le 1 \end{cases} \quad (18)$$

$$a = \begin{cases} 0, & para = 0 \\ -0.5 \times \frac{SGC - HGC}{para}, & otherwise \end{cases} \quad (19)$$

$$b = \begin{cases} 0, & para = 0 \\ \frac{1 - HGC}{para} + \frac{SGC + HGC}{2}, & otherwise \end{cases} \quad (20)$$

$$c = \begin{cases} 0, & para = 0 \\ -\frac{\left((SGC - HGC) \times para - 2(1 - HGC)\right)^2}{8 \times (SGC - HGC) \times para}, & otherwise \end{cases} \quad (21)$$

$$x_{SGC} = \frac{1 - HGC}{SGC - HGC} - \frac{para}{2} \quad (22)$$

$$x_{HGC} = \frac{1 - HGC}{SGC - HGC} + \frac{para}{2} \quad (23)$$

$$exposure = \frac{\textbf{ShadowGainControl}}{4} + 0.5 \quad (24)$$

$$expgain = v\left(\frac{L_{source}}{L_{target}}, L_{target}\right)$$

where: (25)

L_{source} = Maximum Display Mastering Luminance
L_{target} = **TargetedSystemDisplayMaximumLuminance**

$$SGC = expgain \times exposure \quad (26)$$

$$HGC = \frac{\textbf{HighlightGainControl}}{4} \quad (27)$$

$$para = \frac{\textbf{MidToneWidthAdjustmentFactor}}{2} \quad (28)$$

$$a_{Adj} = TMO(a_{BW}) \quad (29)$$

a_{Adj} Is adapted by the fine-tuning curve to arrive at a_{CC}.

$$a_{CC} = \begin{cases} f_{CC_{lum}}(a_{Adj}), & 0 \le a_{Adj} \le 1 \\ a_{Adj}, & otherwise \end{cases} \quad (30)$$

The f_{CClum} is linearly interpolated between given { x_i, y_i } pairs as defined in **ToneMappingOutputFineTuningFunction** in Section 7.3.7. It is a sampled function that uses the generic Interpolation Between Samples method as described in SMPTE ST 2094-1. An example of the f_{CClum} is depicted in Figure B.8.

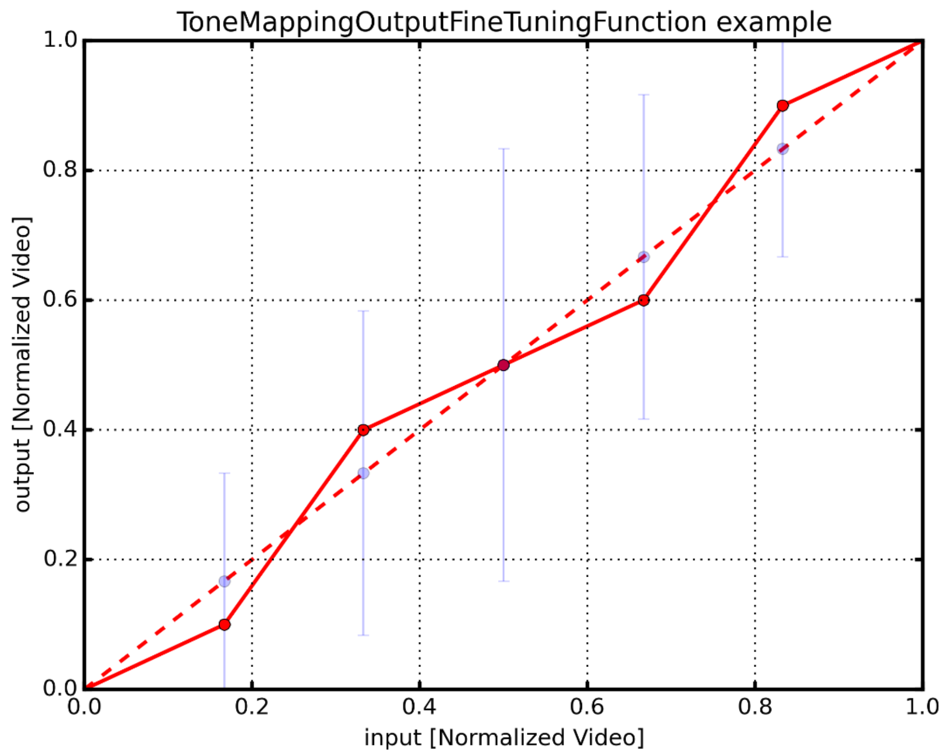


Figure B.8 – Example ToneMappingOutputFineTuningFunction curve

Then a_{LL} is calculated as per equation (32), using the Maximum Luminance of the targeted system L_{target}. Equation (31) is the mathematical inverse function for equation (14). A graphical example of equation (32) is depicted in Figure B.9.

$$v_{inv}(x, L) = \left(\frac{\rho(L)^x - 1}{\rho(L) - 1}\right)^{2.4} \quad (31)$$

$$a_{LL} = v_{inv}(a_{CC}, L_{target})$$

where: (32)

L_{target} = **TargetedSystemDisplayMaximumLuminance**

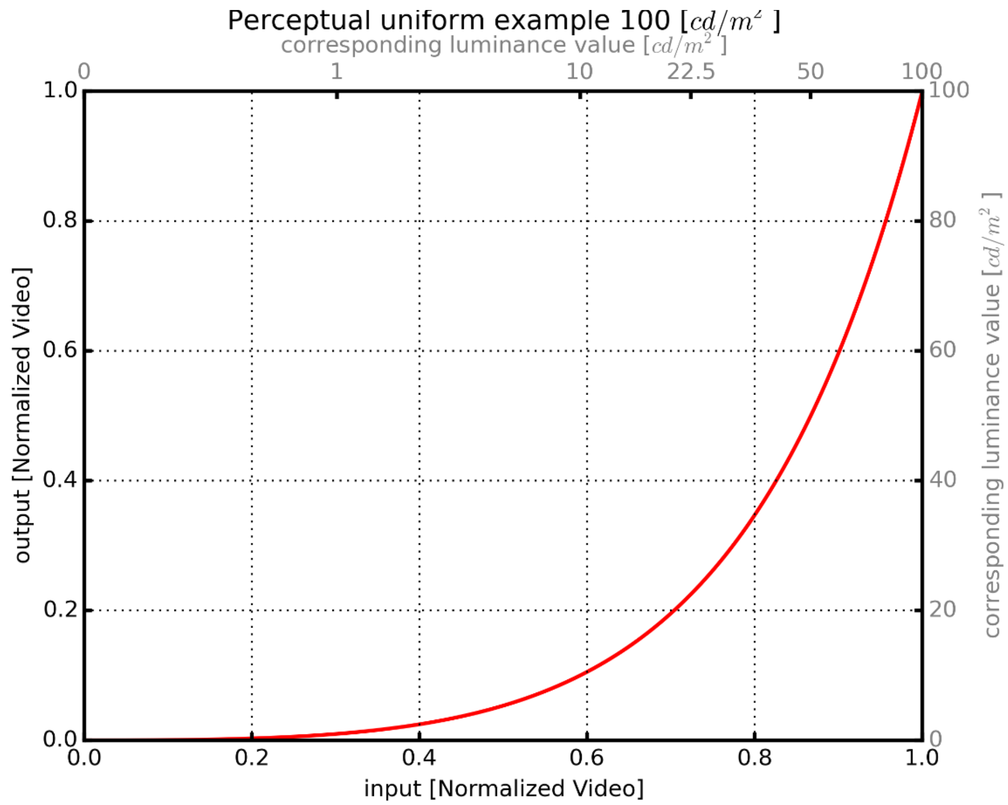


Figure B.9 – Example curve from perceptual to linear based on 100 cd/m²

The value of ω is calculated from a division of a_{LL} by the input a_{RGBY}:

$$\omega = \begin{cases} \dfrac{a_{LL}}{a_{RGBY}}, & blo = 0 \\ \max\left(\dfrac{a_{LL}}{a_{RGBY}}, 1\right), & otherwise \end{cases} \tag{33}$$

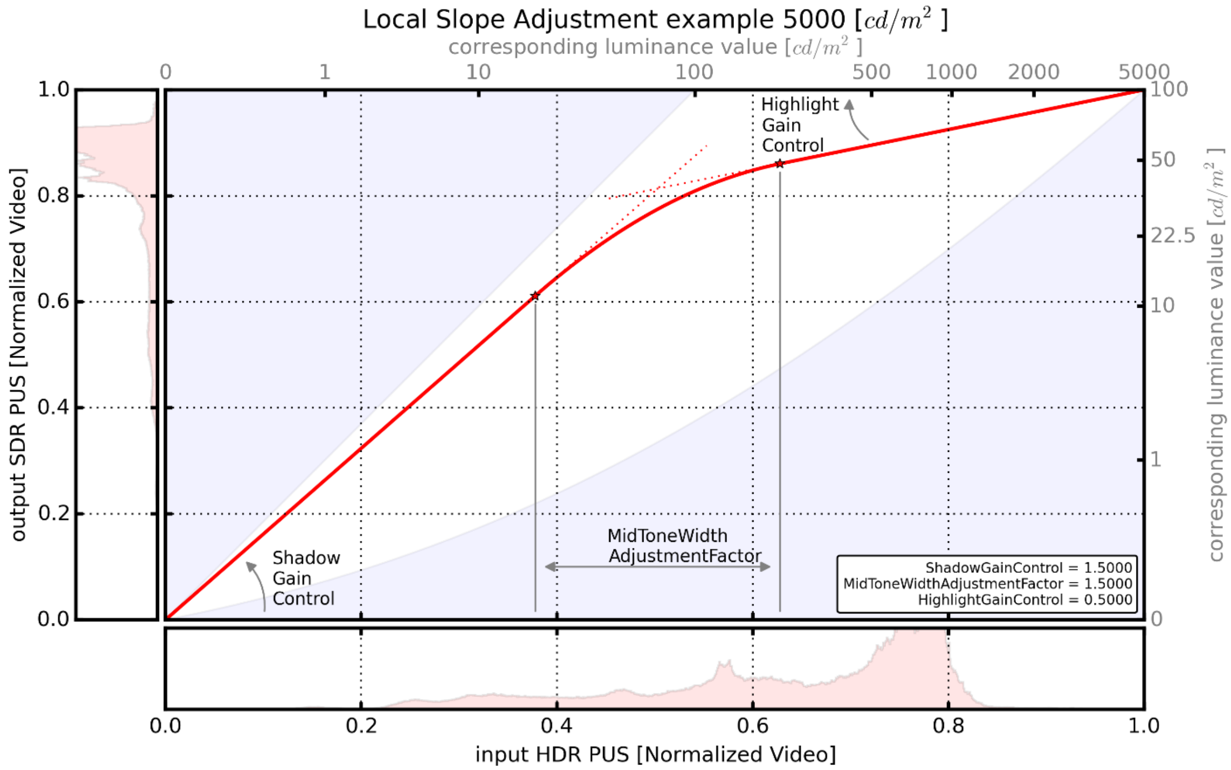
Applying the Tone Mapping process

As the final step of the HDR to SDR processing, the pixel components R_{HDR_S}, G_{HDR_S}, B_{HDR_S} are multiplied by ω to produce the pixel components R_{SDR}, G_{SDR}, B_{SDR}.

$$\begin{pmatrix} R_{SDR} \\ G_{SDR} \\ B_{SDR} \end{pmatrix} = \omega \times \begin{pmatrix} R_{HDR\_S} \\ G_{HDR\_S} \\ B_{HDR\_S} \end{pmatrix} \tag{34}$$

Overview

The result of cascading all the operations in Annex B.4, is a curve as depicted on the bottom side of Figure B.10, taking linear light signals as input and producing linear light signals as output. The top side of Figure B.10 depicts again the control points in the perceptually-uniform domain (same as Figure B.7), and adds an HDR input image histogram and corresponding output image histogram.



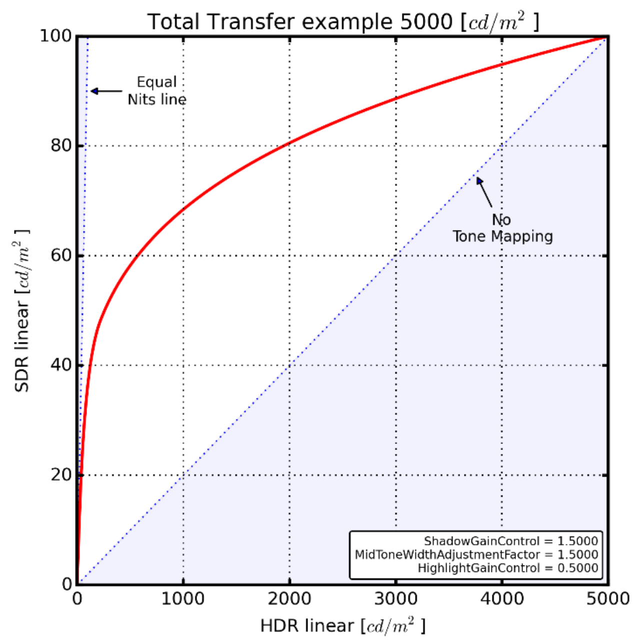


Figure B.10 – Total transfer curve example

Annex C Bibliography (Informative)

SMPTE RP 177:1993, Derivation of Basic Television Color Equations

SMPTE ST 2084:2014, High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays

Recommendation ITU-R BT.2020-2 (10/2015), Parameter values for ultra-high definition television systems for production and international programme exchange