**SMPTE ST 2094-10:2016**

# SMPTE STANDARD

## Dynamic Metadata for Color Volume Transform – Application #1



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## Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices, and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual.

SMPTE ST 2094-10 was prepared by Technology Committee 10E.

## Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this Engineering Document. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

## Introduction

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

The color volume transform for Application #1 is based on a parametric tone mapper. The design of this application is founded on the following requirements:

1. The mapped imagery maintains the contrast characteristics of the input content.

2. When the mapping operation cannot be optimal, compromises can be made in the lower and upper region of the luminance range.

3. The mapping function can be parameterized based on the input content.

4. Manually adjustable parameters are available to provide artistic control of the resulting imagery.

Application #1 takes advantage of a color volume transform that can be performed in color spaces including luminance-chrominance, RGB and color spaces based on the human visual system. Annex B provides a mathematical description of an example color volume transform in RGB output-referred linear light output.

# 1 Scope

This standard specifies the content-dependent color volume transform metadata items for Application #1, a specialized model of the generalized color volume transform defined by the core components document SMPTE ST 2094-1. This color volume transform is based on a parametrically-defined tone mapping curve, the shape of which is defined both by the image essence characteristics (algorithmically computed from the input image essence) as well as by manually-set adjustments. The metadata set supporting the application is generated as a part of the mastering process. The adjustment parameters are decided on as a creative adjustment.

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

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

# 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 PQ-encoded maxRGB

maxRGB values as defined in SMPTE ST 2094-1 and encoded according to the Reference Inverse-EOTF specified in SMPTE ST 2084

## 4.2 selected pixels

pixels within a processing window as defined in SMPTE ST 2094-1

# 5 Application Identification

The **ApplicationIdentifier** value shall be 1 and the **ApplicationVersion** value shall be 0 to identify this version of Application #1.

These two values identify this document as the defining document for the application-specific metadata specified in Section 7.1.

# 6 Color Volume Transform

## 6.1 maxRGB-based Tone Mapping

### 6.1.1 Introduction

The color volume transform for Application #1 is based on parametric tone mapping.

The minimum, average and maximum PQ-encoded maxRGB values are computed from the selected pixels. These metadata items are computed characteristics of the associated image essence and are collected in the metadata group **ImageCharacteristicsLayer**. All remaining metadata items are manual adjustments to the color volume transform and are collected in the metadata group **ManualAdjustmentLayer**.

### 6.1.2 Reduced Pixel Set

The reduced pixel set is the half resolution version of the selected pixels and is used for calculating the minimum, average and maximum PQ-encoded maxRGB value. The reduced pixel set is sampled from the selected pixels throughout all image essence associated with a metadata set.

The reduced pixel set is calculated as follows:

Starting at the upper-left corner ($x_{min}$, $y_{min}$) of the **ProcessingWindow**, the **ProcessingWindow** shall be partitioned into non-overlapping sample areas, each comprising 2x2 pixels. A component-by-component average shall be calculated for the pixels in each sample area. If a sample area falls partly outside the **ProcessingWindow**, only the (1 or 2) pixels that are in the intersection of the sample area and the **ProcessingWindow** shall be used in calculating the average. The reduced pixel set shall be the set of computed averages.

#### 6.1.3 Minimum PQ-encoded maxRGB

The **MinimumPqencodedMaxrgb** shall be the lowest PQ-encoded maxRGB value of the reduced pixel set. Its value shall be a number in the range [0, 1] and in multiples of 0.00001.

#### 6.1.4 Average PQ-encoded maxRGB

The **AveragePqencodedMaxrgb** shall be the average of the PQ-encoded maxRGB values of the reduced pixel set. Its value shall be a number in the range [0, 1] and in multiples of 0.00001.

#### 6.1.5 Maximum PQ-encoded maxRGB

The **MaximumPqencodedMaxrgb** shall be the highest PQ-encoded maxRGB value of the reduced pixel set. Its value shall be a number in the range [0, 1] and in multiples of 0.00001.

#### 6.1.6 Minimum PQ-encoded maxRGB Offset

The **MinimumPqencodedMaxrgbOffset** shall be an offset in the same unit as **MinimumPqencodedMaxrgb** to be added to the **MinimumPqencodedMaxrgb** value. Its value shall be a number in the range [-0.5, 0.5] and in multiples of 0.00001. Its default value shall be 0.0.

#### 6.1.7 Average PQ-encoded maxRGB Offset

The **AveragePqencodedMaxrgbOffset** shall be an offset in the same unit as **AveragePqencodedMaxrgb** to be added to the **AveragePqencodedMaxrgb** value. Its value shall be a number in the range [-0.5, 0.5] and in multiples of 0.00001. Its default value shall be 0.0.

#### 6.1.8 Maximum PQ-encoded maxRGB Offset

The **MaximumPqencodedMaxrgbOffset** shall be an offset in the same unit as **MaximumPqencodedMaxrgb** to be added to the **MaximumPqencodedMaxrgb** value. The value shall be a number in the range [-0.5, 0.5] and in multiples of 0.00001. Its default value shall be 0.0.

#### 6.1.9 Metadata Values Constraints

The metadata items defined in Sections 6.1.3 through 6.1.8 shall meet the following condition:

0 ≤ (**MinimumPqencodedMaxrgb** + **MinimumPqencodedMaxrgbOffset**) <
(**AveragePqencodedMaxrgb** + **AveragePqencodedMaxrgbOffset**) <
(**MaximumPqencodedMaxrgb** + **MaximumPqencodedMaxrgbOffset**) ≤ 1

### 6.2 Offset, Gain and Gamma-based Tone Mapping

#### 6.2.1 Introduction

The tone mapping offset, gain and gamma values shall be applied according to the equation:

$$y = \left(min(max(0, (x \times g) + o), 1)\right)^P \qquad (1)$$

where:

$y$ = output value
$x$ = input value
$g$ = value of Tone Mapping Gain
$o$ = value of Tone Mapping Offset
$P$ = value of Tone Mapping Gamma

#### 6.2.2 Tone Mapping Offset

The **ToneMappingOffset** shall be the Tone Mapping Offset defined in equation (1). Its value shall be in the range [-0.5, 0.5] and in multiples of 0.00001. Its default value shall be 0.0.

#### 6.2.3 Tone Mapping Gain

The **ToneMappingGain** shall be the Tone Mapping Gain defined in equation (1). Its value shall be in the range [0.5, 1.5] and in multiples of 0.0001. Its default value shall be 1.0.

#### 6.2.4 Tone Mapping Gamma

The **ToneMappingGamma** shall be the Tone Mapping Gamma defined in equation (1). Its value shall be in the range [0.5, 1.5] and in multiples of 0.001. Its default value shall be 1.0.

### 6.3 Tone Mapping-based Chroma and Saturation Adjustment

#### 6.3.1 Chroma Compensation Weight

The **ChromaCompensationWeight** shall be an amount of chroma adjustment. The adjustment depends on the luminance and saturation inputs of the tone mapping transform. Its value shall be in the range [-0.5, 0.5] and in multiples of 0.0001. Its default value shall be 0.0.

#### 6.3.2 Saturation Gain

The **SaturationGain** shall be an amount of saturation adjustment. The adjustment depends on the luminance and chroma inputs of the tone mapping transform. Its value shall be in the range [-0.5, 0.5] and in multiples of 0.0001. Its default value shall be 0.0.

### 6.4 Detail Management

#### 6.4.1 Introduction

Detail management is a processing block that controls the appearance of image details after tone mapping. The metadata item specified in Section 6.4.2, Tone Detail Factor, is independent of the processing method.

#### 6.4.2 Tone Detail Factor

The **ToneDetailFactor** shall control the contribution of the detail management function to the tone mapping result. Its value shall be in the range [0, 1] and in multiples of 0.001. Its default value shall be 0.0.

Note: An example use of the tone detail factor is an image peaking operation, where **ToneDetailFactor** specifies no contribution at 0.0 and full contribution at 1.0.

# 7 Application Constraints

## 7.1 Metadata Set

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

- **ApplicationIdentifier** (= 1)
- **ApplicationVersion** (= 0)
- **TimeInterval**

  which shall contain exactly one of all metadata items defined in SMPTE ST 2094-1

  **TimeIntervalStart**
  **TimeIntervalDuration**
- **ProcessingWindow**

  which shall contain exactly one of all metadata items defined in SMPTE ST 2094-1

  **UpperLeftCorner**
  **LowerRightCorner**
  **WindowNumber**
- **TargetedSystemDisplay**

  which shall contain exactly one of all metadata items defined in SMPTE ST 2094-1

  **TargetedSystemDisplayPrimaries**
  **TargetedSystemDisplayWhitePointChromaticity**
  **TargetedSystemDisplayMaximumLuminance**
  **TargetedSystemDisplayMinimumLuminance**
- **ColorVolumeTransform**

  metadata items defined in this document (Section 6)

  **ImageCharacteristicsLayer**, which shall contain exactly one of each of the following named items:

  **MinimumPqencodedMaxrgb**
  **AveragePqencodedMaxrgb**
  **MaximumPqencodedMaxrgb**

  **ManualAdjustmentLayer**, which may contain any combination having zero or one of each of the following named items:

  **MinimumPqencodedMaxrgbOffset**
  **AveragePqencodedMaxrgbOffset**
  **MaximumPqencodedMaxrgbOffset**
  **ToneMappingOffset**
  **ToneMappingGain**
  **ToneMappingGamma**
  **ChromaCompensationWeight**
  **SaturationGain**
  **ToneDetailFactor**

### 7.2 Processing Window Constraints

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 #1 to the Generalized Color Volume Transform Model (Informative)

The diagram in Figure A.1 describes Application #1 Parametric Tone Mapping based color volume transform in the framework of the generalized Color Volume Transform Model described in SMPTE ST 2094-1. The processing blocks applied are Tone Mapping, Gamut Adjustment and Detail Management.

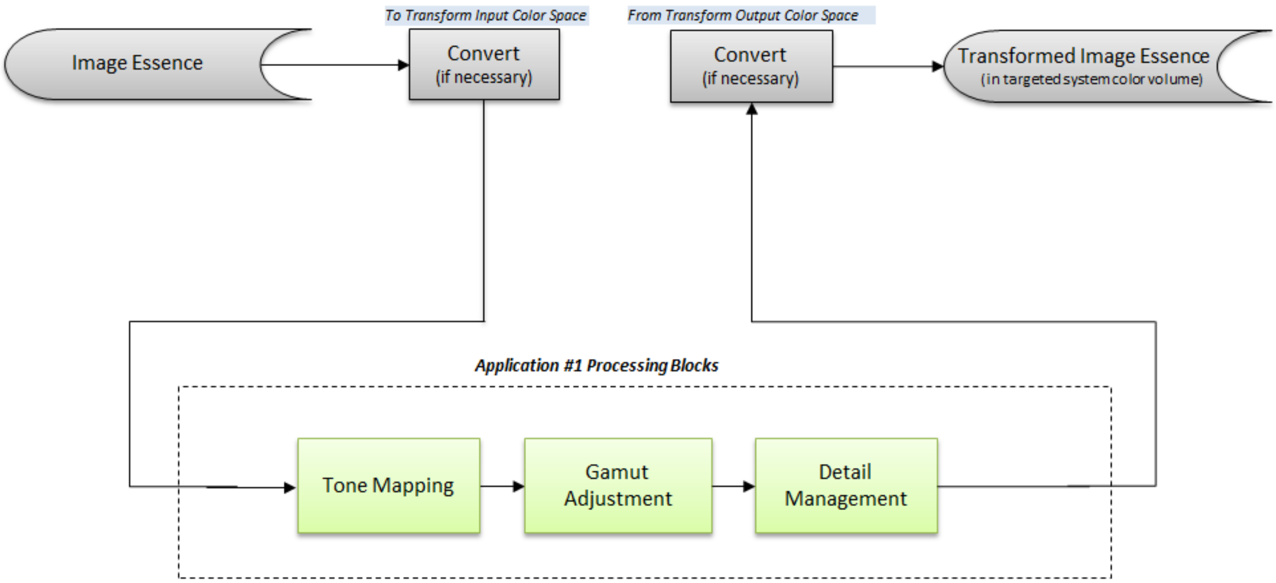


**Figure A.1 – Processing blocks used by Application #1**

# Annex B Parametric Tone Mapping Method Description (Informative)

## B.1 Introduction

The design requirements for Application #1 are fulfilled by adopting an analytically defined sigmoidal curve specified by three control parameters as depicted in Figure B.1. When applied in units of absolute display light output, the dependency of targeted system display luminance in logarithmic scale as a function of the mastering display luminance in logarithmic scale exhibits a linear portion with a gentle rise from minimum (toe) targeted system display luminances and a roll off towards maximum (shoulder) targeted system display luminances. The slope of the linear portion as well as the shapes of the toe and shoulder region are controlled by the three control points. In Application #1, the initial values of the control points, prior to any adjustment, are algorithmically computed from the input pixel values, and are carried as metadata items **MinimumPqencodedMaxrgb**, **AveragePqencodedMaxrgb** and **MaximumPqencodedMaxrgb**.

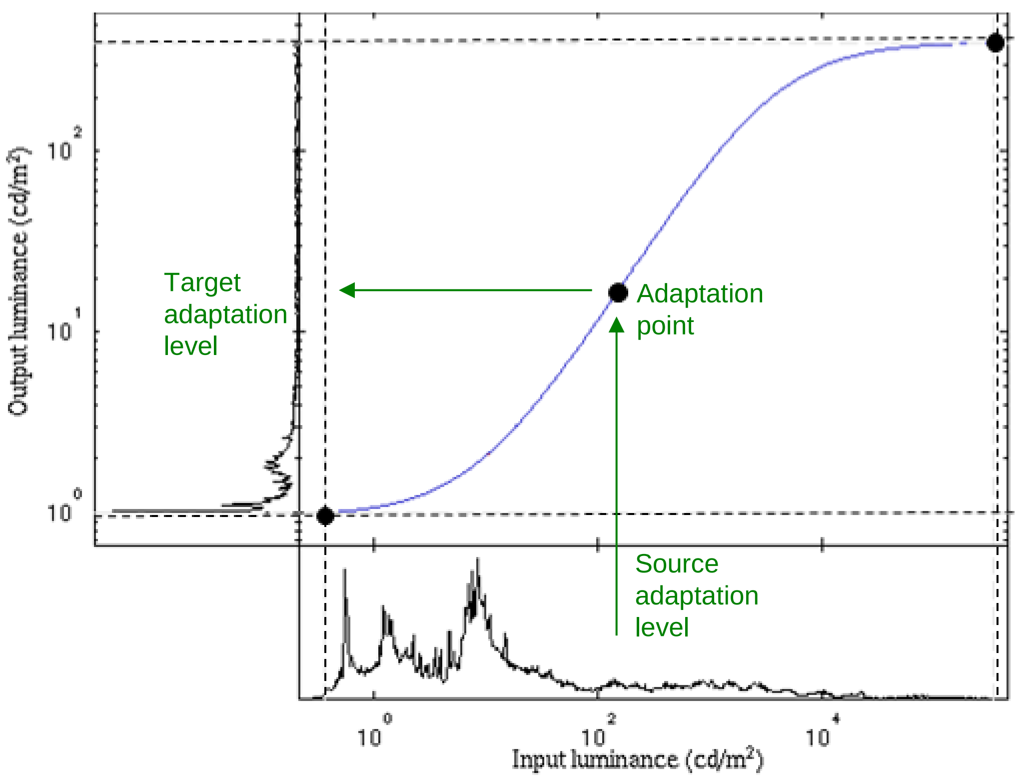


**Figure B.1 – Tone mapping curve for Application #1**

The curve in Figure B.1 can be adjusted manually by offsetting the minimum, average and maximum control points by using the parameters specified in **MinimumPqencodedMaxrgbOffset**, **AveragePqencodedMaxrgbOffset** and **MaximumPqencodedMaxrgbOffset**, respectively. To provide further manual control for the mapping curve, Application #1 also respects the common color correction technique of offsetting the minimum targeted system display output level, applying a gain factor for the entire luminance range and applying a gamma function affecting the mid-tones. These parameters are specified by **ToneMappingOffset**, **ToneMappingGain** and **ToneMappingGamma**.

The slope of the tone mapping curve affects image saturation. A **SaturationGain** control parameter provides a saturation boost or diminution, and a **ChromaCompensationWeight** control parameter provides an overall chrominance compensation weighting factor for the tone mapping. These parameters are intended to be manual adjustments.

Finally, image content with luminances in certain tonal ranges, such as in the toe or shoulder, could suffer severe contrast compression by the tone mapping curve resulting in loss of visual details. There are image processing techniques that can manage perceived visual details in selected tonal ranges. Application #1 provides a single manually set parameter defined by **ToneDetailFactor** to control the contribution from image detail management.

### B.2 Luminance Transform Curve

The sigmoidal tone mapping curve shown in Figure B.1 can be expressed by equation (2):

$$L_m(L) = \left( \frac{c_1 + c_2 \times L^n}{1 + c_3 \times L^n} \right) \qquad (2)$$

where:

$L_m$ = mapped (transformed) luminance in units of cd/m$^2$
$L$ = input luminance in units of cd/m$^2$
$n$ = contrast parameter
$c_1$, $c_2$, $c_3$ = computed coefficients

The contrast parameter $n$ governs the slope in the linear portion of the output light level versus input light level plot shown in Figure B.1. The value of unity for $n$ is used by Application #1 and it is therefore not a metadata item. In fact, the inclusion of the variable in equation (2) is to present the full mathematical form of the particular sigmoidal function. The variable $n$ will be omitted for the remainder of this document.

The three control points on the curve provide sufficient conditions for the determination of the coefficients $c_1$, $c_2$ and $c_3$. The solution is constrained by mapping the input image essence minimum, average and maximum luminance values to the **TargetedSystemDisplayMinimumLuminance**, derived adaptation point and **TargetedSystemDisplayMaximumLuminance**. With the set of variables:

$x_1$ = input image essence minimum luminance value in units of cd/m$^2$
$x_2$ = input image essence average luminance value in units of cd/m$^2$
$x_3$ = input image essence maximum luminance value in units of cd/m$^2$
$y_1$ = **TargetedSystemDisplayMinimumLuminance** in units of cd/m$^2$
$y_2$ = derived targeted system display adaptation point in units of cd/m$^2$
$y_3$ = **TargetedSystemDisplayMaximumLuminance** in units of cd/m$^2$

the luminance mapping constraints can be expressed as:

$$\begin{aligned} L_m(x_1) &= y_1 \\ L_m(x_2) &= y_2 \\ L_m(x_3) &= y_3 \end{aligned} \qquad (3)$$

The targeted system display adaptation point luminance is chosen to be the geometric mean of **TargetedSystemDisplayMinimumLuminance**, **TargetedSystemDisplayMaximumLuminance** and input image essence average luminance value:

$$y_2 = \sqrt{x_2 \times \sqrt{y_3 \times y_1}} \tag{4}$$

As an example, with a targeted system display having a minimum luminance of 0.5 cd/m$^2$ and a maximum luminance of 100 cd/m$^2$, and an input image essence average luminance of 120 cd/m$^2$, equation (4) yields a targeted system display adaptation point luminance of 29 cd/m$^2$. For input image essence average luminance above 3,162 cd/m$^2$, a very bright image, the resulting targeted system display adaptation point luminance exceeds the targeted system display maximum luminance of 100 cd/m$^2$. A simple method to regulate the impractical targeted system display adaptation point is to impose a bound at a fraction (for example 0.8) of the targeted system display maximum luminance value.

The solution to the three simultaneous equations that enforce the mapping constraints in equation (3) provides the three constants $c_1, c_2$ and $c_3$ in the sigmoidal tone mapping curve equation (2):

$$\begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix} = \frac{1}{\alpha} \begin{pmatrix} x_2x_3(y_2 - y_3) & x_1x_3(y_3 - y_1) & x_1x_2(y_1 - y_2) \\ x_3y_3 - x_2y_2 & x_1y_1 - x_3y_3 & x_2y_2 - x_1y_1 \\ x_3 - x_2 & x_1 - x_3 & x_2 - x_1 \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} \tag{5}$$

where:

$$\alpha = x_3y_3(x_1 - x_2) + x_2y_2(x_3 - x_1) + x_1y_1(x_2 - x_3) \tag{6}$$

### B.3 Example Transform Using RGB Color Components

The input pixels are expected to be the RGB linear light output in the mastering display color volume (SMPTE ST 2086). The output pixels are RGB linear light output, transformed for the targeted system display color volume.

The color component $D_i$ (R, G or B) can be transformed using equation (2) with the slope $n$ set to unity:

$$E_i = \left( \frac{c_1 + c_2 \times D_i}{1 + c_3 \times D_i} \right) \tag{7}$$

where:

$E_i$ = mapped (transformed) color component $i$ (R, G or B) in cd/m$^2$
$D_i$ = color component $i$ (R, G or B) in cd/m$^2$
$c_1$, $c_2$, $c_3$ = coefficients computed using equation (5)

Solving for the coefficients $c_1$, $c_2$ and $c_3$ the numerical inputs to equation (5) are the luminances corresponding to the maxRGB-based parameters defined in Section 6.1:

$$x_1 = EOTF_{PQ}(U + dU)$$
$$x_2 = EOTF_{PQ}(V + dV)$$
$$x_3 = EOTF_{PQ}(W + dW)$$

and the **TargetedSystemDisplay** metadata items:

$y_1$ = **TargetedSystemDisplayMinimumLuminance**

$y_3$ = **TargetedSystemDisplayMaximumLuminance**

with:

$$y_2 = \sqrt{x_2 \times \sqrt{y_3 \times y_1}}$$

where:

$EOTF_{PQ}\ (\,)$= Reference Electro-Optical Transfer Function as defined in SMPTE ST 2084

$U$ = **MinimumPqencodedMaxrgb** as defined in Section 6.1.3

$dU$ = **MinimumPqencodedMaxrgbOffset** as defined in Section 6.1.6

$V$ = **AveragePqencodedMaxrgb** as defined in Section 6.1.4

$dV$ = **AveragePqencodedMaxrgbOffset** as defined in Section 6.1.7

$W$ = **MaximumPqencodedMaxrgb** as defined in Section 6.1.5

$dW$ = **MaximumPqencodedMaxrgbOffset** as defined in Section 6.1.8

The tone mapping offset, gain and gamma introduced in Section 6.2 allow for manual adjustments to the tone mapping curve. The adjusted color component $F_i$ (R, G or B) in units of cd/m$^2$ is defined as:

$$F_i = \left(min\left(max\left(0, \left((E_i/y_3) \times g\right) + o\right), 1\right)\right)^P \times y_3 \qquad (8)$$

where:

$F_i$ = adjusted color component $i$ (R, G or B) in units of cd/m$^2$

$E_i$ = mapped (transformed) color component $i$ (R, G or B) in units of cd/m$^2$

$y_3$ = **TargetedSystemDisplayMaximumLuminance**

$g$ = **ToneMappingGain** as defined in Section 6.2.3

$o$ = **ToneMappingOffset** as defined in Section 6.2.2

$P$ = **ToneMappingGamma** as defined in Section 6.2.4

The normalization of the input color components by the **TargetedSystemDisplayMaximumLuminance**, $y_3$, is necessary for the offset, gain and gamma tone mapping adjustments. The output adjusted color components are then scaled by the same factor, producing linear light output in units of cd/m$^2$.

The luminance of the adjusted color components, output of equation (8), can be computed using the targeted system display primaries and white point chromaticities. For example, using the chromaticities for Digital

Cinema Reference Projector primaries (SMPTE RP 431-2) and D65 white point, SMPTE EG 432-1 provides the equation for luminance $Y$ calculated from adjusted color components $F_i$ (R, G and B):

$$Y = 0.22897 \times F_R + 0.69174 \times F_G + 0.07929 \times F_B$$

When the tone mapping curve in equation (2) is applied to the color components R, G and B, unless the image is entirely achromatic, the tonal contrast will affect the saturation of the image. It is commonly observed that increasing or reducing the contrast will increase or decrease, respectively, the saturation of the resulting image. In Application #1, a saturation gain and a chrominance compensation function are included in Section 6.3. The overall color volume transform becomes:

$$G_i = F_i \times \left( (1+c) \times \frac{F_i}{Y} \right)^S \qquad (9)$$

where:

$G_i$ = output light level of color component $i$ (R, G or B) in units of cd/m$^2$
$F_i$ = the adjusted color component $i$ (R, G, or B) in units of cd/m$^2$
$Y$ = the luminance of the adjusted pixel according to equation (8) in units of cd/m$^2$
$c$ = **ChromaCompensationWeight** as defined in Section 6.3.1
$S$ = **SaturationGain** as defined in Section 6.3.2

The final parameter **ToneDetailFactor** $T$ defined in 6.4 allows for a controlled amount of contribution from the detail management processing to the color volume transform output image. The symbol $p_i$ represents an output pixel of linear light RGB color components ($G_1$ = R, $G_2$ = G, $G_3$ = B) resulting from equation (9) and the symbol $q_i$ represents an output pixel with detail management processing. The effect of detail management processing is controlled by the parameter **ToneDetailFactor** $T$ using a pixel blending operation between the color volume transform output and its processed version:

$$r_i = p_i \times (1 - T) + q_i \times T$$

where:

$r_i$ = final transformed output pixel color component R, G or B
$p_i$ = color volume transform output pixel according to equation (9)
$T$ = **ToneDetailFactor** as defined in Section 6.4.2
$q_i$ = color volume transform output pixel that is processed by detail management processing

## Annex C Bibliography (Informative)

SMPTE RP 431-2:2011, D-Cinema Quality — Reference Projector and Environment

SMPTE EG 432-1:2010, Digital Source Processing — Color Processing for D-Cinema

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