SMPTE STANDARD

BT.2100 RGB Conversion to IPT-PQ-C2 Color Space for High Dynamic Range and Wide Color Gamut Images

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Foreword

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SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual. This SMPTE Engineering Document was prepared by Technology Committee 10E Essence.

Introduction

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

The design of the IPT color space was based on the human visual system with three photo receptors sensitive to L (long), M (medium), and S (short) wavelengths. The original IPT color space is historical and not part of this document. Variations of the color appearance model in LMS were developed in support of high dynamic range (HDR) imaging. The IPT-PQ color representation is arrived at using: i) a perceptual based non-linear coding of LMS; and ii) a color differencing process to separate the signal into three distinct pathways, i.e., the light-dark Intensity axis, I, the red-green Protan isoluminant axis, P, and the yellow-blue Tritan isoluminant axis, T.

IPT-PQ-C2 is not intended as a mastering format or for production interchange and should be used only for consumer distribution.

SMPTE draws attention to the fact that it is claimed that compliance with this Standard may involve the use of one or more patents or other intellectual property rights (collectively, "IPR"). The Society takes no position concerning the evidence, validity, or scope of this IPR.

Each holder of claimed IPR has assured the Society that it is willing to License all IPR it owns, and any third party IPR it has the right to sublicense, that is essential to the implementation of this Standard to those (Members and non-Members alike) desiring to implement this Standard under reasonable terms and conditions, demonstrably free of discrimination. Each holder of claimed IPR has filed a statement to such effect with SMPTE. Information may be obtained from the Director, Standards & Engineering at SMPTE Headquarters.

Attention is also drawn to the possibility that elements of this Standard may be subject to IPR other than those identified above. The Society shall not be responsible for identifying any or all such IPR.

1 Scope

This document defines IPT-PQ-C2 computations for Recommendation ITU-R BT.2100 signals.

2 Conformance

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 clause 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 that, through reference in this text, constitute provisions of this standard. Dated references require that the specific edition cited shall be used as the reference. Undated citations refer to the edition of the referenced document (including any amendments) current at the date of publication of this document. All standards are subject to revision, and users of this engineering document are encouraged to investigate the possibility of applying the most recent edition of any undated reference.

SMPTE ST 2084:2014, *High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays*. https://doi.org/10.5594/SMPTE.ST2084.2014

Recommendation ITU-R BT.2100, Image parameter values for high dynamic range television for use in production and international programme exchange

4 Terms and Definitions

For the purposes of this document, the following terms and definitions apply:

4.1
color value *{R, G, B}*

R, G, B triplet that is directly proportional to a displayed color's red, green, and blue linear optical power, respectively, normalized to the range of [0, 1], where a value of {0, 0, 0} represents no emitted power and a value of {1, 1, 1} represents the Reference White specified by Recommendation ITU-R BT.2100 at a display luminance of 10000 cd/m^2

4.2
color value *{I, P, T}*

I, P, T triplet representing a color using the light-dark Intensity axis, I, the red-green Protan isoluminant axis, P, and the yellow-blue Tritan isoluminant axis, T; with values in the range of [0, 1] for I and [−0.5, 0.5] for P and T

5 Mathematical Functions

5.1 InversePQ(*v*)

The function inversePQ(*v*) shall apply the Inverse-EOTF Non-linear Encoding Equation defined by SMPTE ST 2084 to the input value *v*. The input value shall be in the range [0, 1].

NOTE The inversePQ function takes a normalized linear light value as input. Therefore, the Inverse-EOTF Normalization Equation defined by SMPTE ST 2084 with a divider of 10000 to the input value is not included.

5.2 PQ(*v*)

The function PQ(*v*) shall apply the EOTF Linearization Equation defined by SMPTE ST 2084 to the input value *v*. The input value shall be in the range [0, 1].

NOTE The PQ function produces a normalized linear color value as output. Therefore, the EOTF Level Calibration Equation defined by SMPTE ST 2084 with a multiplier of 10000 to the output value is not included.

5.3 LMS2IPT

LMS2IPT shall be defined as the following matrix as specified in Formula (1):

$$LMS2IPT = \begin{bmatrix} 1638 & 1638 & 820 \\ 18248 & -19870 & 1622 \\ 3300 & 1463 & -4763 \end{bmatrix} / 4096 \quad (1)$$

6 Linear RGB to IPT-PQ-C2 Conversions

6.1 General (Informative)

The conversion of colors from Recommendation ITU-R BT.2100 to IPT-PQ-C2 is specified in Clause 6.2.

The conversion of colors from RGB to IPT-PQ-C2 includes a conversion matrix from RGB to LMS color representation (Formula (2)) followed by the transform to non-linear LMS values (Formula (3)), then to IPT color representation (Formula (4)).

To simplify the notation, the I, P, and T symbols introduced in this document do not employ the prime symbols.

If 10-bit R′G′B′ PQ code values are input to an IPT-PQ-C2 encoder, then there will be significant errors when decoding the IPT-PQ-C2 values back to 10-bit R′G′B′ PQ if 32-bit float precision arithmetic is used, even when the IPT-PQ-C2 values are not quantized.

6.2 Color value *{R, G, B}* in Recommendation ITU-R BT.2100 to IPT-PQ-C2

Conversion of a color value *{R, G, B}* in Recommendation ITU-R BT.2100 to a color value *{I, P, T}* in IPT-PQ-C2 shall be performed as specified in this clause.

The input R, G, B components as a vector shall be transformed to an intermediate vector by Formula (2).

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 1747 & 2169 & 180 \\ 673 & 3029 & 394 \\ 50 & 207 & 3839 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} / 4096 \tag{2}$$

The intermediate vector shall have each component transformed by Formula (3).

$$\begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} = \begin{bmatrix} inversePQ(L) \\ inversePQ(M) \\ inversePQ(S) \end{bmatrix} \tag{3}$$

The output I, P, T components as a vector shall be computed from the non-linear intermediate components L′, M′, S′ by Formula (4).

$$\begin{bmatrix} I \\ P \\ T \end{bmatrix} = LMS2IPT \cdot \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \tag{4}$$