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| *Title:* | **Generalized Constant and Non-Constant Luminance Code Points** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Proposal | | |
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# Abstract

This contribution proposes two additional code point values for the Matrix Coefficients VUI element of HEVC. In particular, we propose the signalling of a generalized Constant Luminance and of a generalized Non-Constant Luminance difference signal representation where the matrix/difference coefficients are directly and optimally derived through the colour primaries characteristics of the signal. This permits us to signal such representations for colour primary and transfer characteristics entries already defined in the HEVC specification, e.g. P3D65 or P22, that currently do not have matching matrix coefficient entry, as well as new colour primary entries that may be specified in the future without having to explicitly specify their corresponding matrix coefficient entries.

# Introduction / Problem Statement

The MPEG-H part 2/HEVC, as well as the MPEG-4 AVC and ISO/IEC 23001-8 specifications, provide for the signaling of information that can describe the colour volume and representation format of an underlying video signal. In particular, these include:

1. a colour primaries syntax element, which indicates the chromaticity coordinates of the source colour primaries,
2. a transfer characteristics syntax element, which indicates the opto-electronic transfer function applied onto the material, and
3. a matrix coefficients syntax element, which specifies the coefficients and describes the process of deriving the luma and color/chroma difference signals from the green, blue, and red, or X, Y, and Z primaries.

Using these syntax elements an encoder can signal to an intended device the necessary information for appropriately reconstructing and displaying the video signal after decompression. Currently, the most commonly supported video formats in the industry are supported and can be signalled with these parameters, such as colour primaries including BT.601, BT.709, BT.2020, P3 D65, P3 DCI, XYZ, a variety of Standard Dynamic Range and High Dynamic Range transfer functions, as well as the YCgCo, BT.601, BT.709, and BT.2020 non-constant luminance, BT.2020 constant luminance, and Y’D’zD’x representations among others. An encoder could, for example, signal that the current video signal uses the BT.2020 colour primaries, the BT.2020 or ST 2084 transfer function, and the BT.2020 non-constant luminance representation.

Unfortunately, the current signalling has some limitations. Even though the non-constant luminance and to some extent the constant luminance representations are the most commonly used formats deployed for video applications, the matrix coefficients syntax element currently supports a limited set of such entries. It could also be said that these entries are optimized for video signals using only certain colour primaries. For example, even though the current specification can support video signals with P3D65 colour primaries, there is no corresponding non-constant luminance or constant luminance matrix coefficients entry. In fact, many existing applications end up reusing the BT.709 non-constant luminance representation when dealing with such format, which could be said is suboptimal given the additional distortion that this may introduce to all color components especially after compression.

It would be highly desirable to introduce values for the matrix coefficients syntax element that could enable the signalling of the optimal non-constant and constant luminance representations given the colour primaries of the signal. Such signalling should also be generic enough so as to avoid having to specify and waste additional values of the matrix coefficients syntax element if new colour primaries entries are defined in the future.

In this contribution we present such generalized representations, given the procedure specified in the SMPTE recommended practice document, RP 177-1993 [7]. In particular, that recommendation provides a mechanism of deriving the basic color equations that describe the relationships between the RGB signals and the CIE XYZ values. This permits us to determine the RGB to Y’ conversion and essentially the “optimal” KR and KB coefficients for a particular color representation, directly from the colour primaries chromaticity coordinates, as specified by the colour\_primaries syntax element. Given these parameters, as well as information about the transfer characteristics of the signal, we can then use the already defined non-constant luminance and constant luminance equations already specified in the HEVC specification, without any further modifications.

# Proposed Text

**matrix\_coeffs** describes the matrix coefficients used in deriving luma and chroma signals from the green, blue, and red, or Y, Z, and X primaries, as specified in Table E.1.

matrix\_coeffs shall not be equal to 0 unless one or more of the following conditions are true:

– BitDepthC is equal to BitDepthY.

– chroma\_format\_idc is equal to 3 (4:4:4).

The specification of the use of matrix\_coeffs equal to 0 under all other conditions is reserved for future use by ITU‑T | ISO/IEC.

matrix\_coeffs shall not be equal to 8 unless one of the following conditions is true:

– BitDepthC is equal to BitDepthY,

– BitDepthC is equal to BitDepthY + 1 and chroma\_format\_idc is equal to 3 (4:4:4).

The specification of the use of matrix\_coeffs equal to 8 under all other conditions is reserved for future use by ITU‑T | ISO/IEC.

When the matrix\_coeffs syntax element is not present, the value of matrix\_coeffs is inferred to be equal to 2 (unspecified).

The interpretation of matrix\_coeffs, together with colour\_primaries and transfer\_characteristics, is specified by the equations below.

NOTE 1 – For purposes of YZX representation when matrix\_coeffs is equal to 0, the symbols R, G, and B are substituted for X, Y, and Z, respectively, in the following descriptions of Equations E‑1 to E‑3, E‑7 to E‑9, E‑13 to E‑15, and E‑19 to E‑21.

ER, EG, and EB are defined as "linear-domain" real-valued signals based on the indicated colour primaries before application of the transfer characteristics function. The application of the transfer characteristics function is denoted by ( x )′ for an argument x. The signals E′R, E′G, and E′B are determined by application of the transfer characteristics function as follows:

E′R = ( ER )′ (E‑1)

E′G = ( EG )′ (E‑2)

E′B = ( EB )′ (E‑3)

The range of E′R, E′G, and E′B is specified as follows:

– If transfer\_characteristics is not equal to 11 or 12, E′R, E′G, and E′B are real numbers with values in the range of 0 to 1 inclusive.

– Otherwise, (transfer\_characteristics is equal to 11 (IEC 61966-2-4) or 12 (Rec. ITU-R BT.1361 extended colour gamut system) ), E′R, E′G and E′B are real numbers with a larger range not specified in this Specification.

Nominal white is specified as having E′R equal to 1, E′G equal to 1, and E′B equal to 1.

Nominal black is specified as having E′R equal to 0, E′G equal to 0, and E′B equal to 0.

The interpretation of matrix\_coeffs is specified as follows:

– If video\_full\_range\_flag is equal to 0, the following applies:

– If matrix\_coeffs is equal to 1, 4, 5, 6, 7, 9, 10, 11, 12, or 13, the following equations apply:

Y = Clip1Y( Round( ( 1 << ( BitDepthY − 8 ) ) \* ( 219 \* E′Y + 16 ) ) ) (E‑4)

Cb = Clip1C( Round( ( 1 << ( BitDepthC − 8 ) ) \* ( 224 \* E′PB + 128 ) ) ) (E‑5)

Cr = Clip1C( Round( ( 1 << ( BitDepthC − 8 ) ) \* ( 224 \* E′PR + 128 ) ) ) (E‑6)

– Otherwise, if matrix\_coeffs is equal to 0 or 8, the following equations apply:

R = Clip1Y( ( 1 << ( BitDepthY − 8 ) ) \* ( 219 \* E′R + 16 ) ) (E‑7)

G = Clip1Y( ( 1 << ( BitDepthY − 8 ) ) \* ( 219 \* E′G + 16 ) ) (E‑8)

B = Clip1Y( ( 1 << ( BitDepthY − 8 ) ) \* ( 219 \* E′B + 16 ) ) (E‑9)

– Otherwise, if matrix\_coeffs is equal to 2, the interpretation of the matrix\_coeffs syntax element is unknown or is determined by the application.

– Otherwise (matrix\_coeffs is not equal to 0, 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, or 13), the interpretation of the matrix\_coeffs syntax element is reserved for future definition by ITU‑T | ISO/IEC.

– Otherwise (video\_full\_range\_flag is equal to 1), the following applies:

– If matrix\_coeffs is equal to 1, 4, 5, 6, 7, 9, 10, 12, or 13 the following equations apply:

Y = Clip1Y( Round( ( ( 1 << BitDepthY ) − 1 ) \* E′Y ) ) (E‑10)

Cb = Clip1C( Round( ( ( 1 << BitDepthC ) − 1 ) \* E′PB + ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑11)

Cr = Clip1C( Round( ( ( 1 << BitDepthC ) − 1 ) \* E′PR + ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑12)

– Otherwise, if matrix\_coeffs is equal to 0 or 8, the following equations apply:

R = Clip1Y( ( ( 1 << BitDepthY ) − 1 ) \* E′R ) (E‑13)

G = Clip1Y( ( ( 1 << BitDepthY ) − 1 ) \* E′G ) (E‑14)

B = Clip1Y( ( ( 1 << BitDepthY ) − 1 ) \* E′B ) (E‑15)

– Otherwise, if matrix\_coeffs is equal to 2, the interpretation of the matrix\_coeffs syntax element is unknown or is determined by the application.

– Otherwise (matrix\_coeffs is not equal to 0, 1, 2, 4, 5, 6, 7, 8, 9, 10, 12, or 13), the interpretation of the matrix\_coeffs syntax element is reserved for future definition by ITU‑T | ISO/IEC. Reserved values for matrix\_coeffs shall not be present in bitstreams conforming to this version of this Specification. Decoders shall interpret reserved values of matrix\_coeffs as equivalent to the value 2.

If matrix\_coeffs is equal to 12 or 13 then the constants KR and KB are computed, using the colour primaries chromaticity coordinates (xR, yR), (xG, yG), (xB, yB), and (xW, yW), for red, green, blue, and white respectively, as specified by the colour\_primaries syntax element, as follows:

– First compute the z coordinates for all colour primaries using the equations:

zR = 1 – (xR + yR) (E‑16)

zG = 1 – (xG + yG) (E‑17)

zB = 1 – (xB + yB) (E‑18)

zW = 1 – (xW + yW) (E‑19)

– Then the constants KR and KB can be computed as:

(E‑20)

(E‑21)

The variables E′Y, E′PB, and E′PR (for matrix\_coeffs not equal to 0 or 8) or Y, Cb, and Cr (for matrix\_coeffs equal to 0 or 8) are specified as follows:

– If matrix\_coeffs is not equal to 0, 8, 10, 11, or 13 the following equations apply:

E′Y = KR \* E′R + ( 1 − KR − KB ) \* E′G + KB \* E′B (E‑22)

E′PB = 0.5 \* ( E′B − E′Y ) ÷ ( 1 − KB ) (E‑23)

E′PR = 0.5 \* ( E′R − E′Y ) ÷ ( 1 − KR ) (E‑24)

NOTE 2 – E′Y is a real number with the value 0 associated with nominal black and the value 1 associated with nominal white. E′PB and E′PR are real numbers with the value 0 associated with both nominal black and nominal white. When transfer\_characteristics is not equal to 11 or 12, E′Y is a real number with values in the range of 0 to 1 inclusive. When transfer\_characteristics is not equal to 11 or 12, E′PB and E′PR are real numbers with values in the range of −0.5 to 0.5 inclusive. When transfer\_characteristics is equal to 11 (IEC 61966‑2‑4), or 12 (ITU‑R BT.1361 extended colour gamut system), E′Y, E′PB and E′PR are real numbers with a larger range not specified in this Specification.

– Otherwise, if matrix\_coeffs is equal to 0, the following equations apply:

Y = Round( G ) (E‑25)

Cb = Round( B ) (E‑26)

Cr = Round( R ) (E‑27)

– Otherwise, if matrix\_coeffs is equal to 8, the following applies:

– If BitDepthC is equal to BitDepthY, the following equations apply:

Y = Round( 0.5 \* G + 0.25 \* ( R + B ) ) (E‑28)

Cb = Round( 0.5 \* G − 0.25 \* ( R + B ) ) + ( 1 << ( BitDepthC − 1 ) ) (E‑29)

Cr = Round( 0.5 \* (R − B ) ) + ( 1 << ( BitDepthC − 1 ) ) (E‑30)

NOTE 3 – For purposes of the YCgCo nomenclature used in Table E.1, Cb and Cr of Equations E‑29 and E‑30 may be referred to as Cg and Co, respectively. The inverse conversion for the above three equations should be computed as:

t = Y − ( Cb − ( 1 << ( BitDepthC − 1 ) ) ) (E‑31)

G = Clip1Y( Y + ( Cb − ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑32)

B = Clip1Y( t − ( Cr − ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑33)

R = Clip1Y( t + ( Cr − ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑34)

– Otherwise (BitDepthC is not equal to BitDepthY), the following equations apply:

Cr = Round( R ) − Round( B ) + ( 1 << ( BitDepthC − 1 ) ) (E‑35)

t = Round( B ) + ( ( Cr − ( 1 << ( BitDepthC − 1 ) ) ) >> 1 ) (E‑36)

Cb = Round( G ) − t + ( 1 << ( BitDepthC − 1 ) ) (E‑37)

Y = t + ( ( Cb − ( 1 << ( BitDepthC − 1 ) ) ) >> 1 ) (E‑38)

NOTE 4 – For purposes of the YCgCo nomenclature used in Table E.1, Cb and Cr of Equations E‑37 and E‑35 may be referred to as Cg and Co, respectively. The inverse conversion for the above four equations should be computed as.

t = Y − ( ( Cb − ( 1 << ( BitDepthC − 1 ) ) ) >> 1 ) (E‑39)

G = Clip1Y( t + ( Cb − ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑40)

B = Clip1Y( t − ( ( Cr − ( 1 << ( BitDepthC − 1 ) ) ) >> 1 ) ) (E‑41)

R = Clip1Y( B + ( Cr − ( 1 << ( BitDepthC − 1 ) ) ) ) (E‑42)

– Otherwise, if matrix\_coeffs is equal to 10 or 13, the signal E′Y is determined by application of the transfer characteristics function as follows, and Equations E‑45 to E‑52 apply for specification of the signals E′PB and E′PR:

EY = KR \* ER + ( 1 − KR − KB ) \* EG + KB \* EB (E‑43)

E′Y = ( EY )′ (E‑44)

NOTE 5 – In this case, EY is defined from the "linear-domain" signals for ER, EG, and EB, prior to application of the transfer characteristics function, which is then applied to produce the signal E′Y. EY and E′Y are analogue with the value 0 associated with nominal black and the value 1 associated with nominal white.

E′PB = ( E′B − E′Y ) ÷ ( 2 \* NB ) for − NB <= E′B − E′Y  <= 0 (E‑45)

E′PB = ( E′B − E′Y ) ÷ ( 2 \* PB ) for 0 < E′B − E′Y <= PB (E‑46)

E′PR = ( E′R − E′Y ) ÷ ( 2 \* NR ) for − NR <= E′R − E′Y  <= 0 (E‑47)

E′PR = ( E′R − E′Y ) ÷ ( 2 \* PR ) for 0 < E′R − E′Y  <= PR (E‑48)

where the constants NB, PB, NR, and PR are determined by application of the transfer characteristics function to expressions involving the constants KB and KR as follows:

NB = ( 1 − KB )′ (E‑49)

PB = 1 − ( KB )′ (E‑50)

NR = ( 1 − KR )′ (E‑51)

PR = 1 − (  KR )′ (E‑52)

– Otherwise (matrix\_coeffs is equal to 11), the following equations apply:

E′Y = E′G (E‑53)

E′PB = 0.5 \* ( 0.986566 \* E′B − E′Y ) (E‑54)

E′PR = 0.5 \* ( E′R − 0.991902 \* E′Y ) (E‑55)

NOTE 6 – In this case, E′PB may be referred to as D′Z and E′PR may be referred to as D′X.

Table E.1 – Matrix coefficients

|  |  |  |
| --- | --- | --- |
| Value | Matrix | Informative remark |
| 0 | Identity | The identity matrix.  Typically used for GBR (often referred to as RGB); however, may also be used for YZX (often referred to as XYZ); see Equations E‑20 to E‑22  IEC 61966-2-1 (sRGB)  Society of Motion Picture and Television Engineers ST 428-1 |
| 1 | KR = 0.2126; KB = 0.0722 | ITU‑R Rec. BT.709-5  ITU‑R Rec. BT.1361 conventional colour gamut system and extended colour gamut system  IEC 61966-2-1 (sYCC)  IEC 61966-2-4 xvYCC709  Society of Motion Picture and Television Engineers RP 177 (1993) Annex B |
| 2 | Unspecified | Image characteristics are unknown or are determined by the application. |
| 3 | Reserved | For future use by ITU‑T | ISO/IEC |
| 4 | KR = 0.30; KB = 0.11 | United States Federal Communications Commission Title 47 Code of Federal Regulations (2003) 73.682 (a) (20) |
| 5 | KR = 0.299; KB = 0.114 | ITU‑R Rec. BT.470‑6 System B, G (historical)  ITU‑R Rec. BT.601‑6 625  ITU‑R Rec. BT.1358 625  ITU‑R Rec. BT.1700 625 PAL and 625 SECAM  IEC 61966-2-4 xvYCC601  (functionally the same as the value 6) |
| 6 | KR = 0.299; KB = 0.114 | ITU‑R Rec. BT.601‑6 525  ITU‑R Rec. BT.1358 525  ITU‑R Rec. BT.1700 NTSC  Society of Motion Picture and Television Engineers 170M (2004)  (functionally the same as the value 5) |
| 7 | KR = 0.212; KB = 0.087 | Society of Motion Picture and Television Engineers 240M (1999) |
| 8 | YCgCo | See Equations E‑23 to E‑37 |
| 9 | KR = 0.2627; KB = 0.0593 | Rec. ITU-R BT.2020 non-constant luminance system  See Equations E‑17 to E‑19 |
| 10 | KR = 0.2627; KB = 0.0593 | Rec. ITU-R BT.2020 constant luminance system  See Equations E‑38 to E‑47 |
| 11 | Y′D′ZD′X | Society of Motion Picture and Television Engineers ST 2085 (2015)  See Equations E‑48 to E‑50. |
| 12 | See Equations E‑16 to E‑21 | Generalized non-constant luminance system  See Equations E‑17 to E‑19 |
| 13 | See Equations E‑16 to E‑21 | Generalized constant luminance system  See Equations E‑38 to E‑47 |
| 14..255 | Reserved | For future use by ITU‑T | ISO/IEC |

# Conclusion

This contribution proposes the introduction of two additional code points to be assigned to the matrix coefficients syntax element. The first will correspond to a generalized non-constant luminance system and the second to a constant luminance system, with their corresponding matrix coefficients parameters derived directly from the colour\_primaries information. It is further suggested that these new code points are adopted also in MPEG-4 AVC as well as in ISO/IEC 23001-8.

# References

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2. ISO/IEC 23001-8:2014, Information technology — MPEG systems technologies — Part 8: Coding-independent code-points
3. Recommendation ITU-R BT.2020, “Parameter values for ultra-high definition television systems for production and international programme exchange” (2012).
4. Recommendation ITU-R BT.709-5, “Parameter values for the HDTV standards for production and international programme exchange”
5. Recommendation ITU-R BT.601-6, “Studio encoding parameters of digital television for standard 4:3 and wide screen 16:9 aspect ratios”
6. SMPTE ST 2084:2014, “High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays”, 2014
7. SMPTE RP 177:1993, “Derivation of Basic Television Color Equations”, 1993

# Patent rights declaration(s)

**Apple Inc does not have any current or pending patent rights relating to the technology described in this contribution.**

**MovieLabs Inc does not have any current or pending patent rights relating to the technology described in this contribution.**