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| *Title:* | **AHG14: suggested draft text for HDR/WCG technology for SDR backward compatibility, display adaptation, and quality enhancement processing** | | |
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# Abstract

This document relates to high dynamic range (HDR) and wide color gamut (WCG) video distribution, based on HEVC single-layer or dual-layer coding. Its provides a suggested draft text for HDR and WCG video processing guidelines, using HEVC signaling, for SDR backward compatibility, display adaptation capabilities, and quality enhancement processing. It includes a description of HEVC signaling mechanisms, and of pre-encoding, coding, and post-decoding steps, enabling to address these three features. For SDR backward compatibility, the usage of HEVC VUI and SEI messages with single-layer coding, and of dual-layer SHVC coding, is discussed. For display adaptation, the document describes how HEVC SEI messages can be used. For quality enhancement processing, and in particular for improved coding efficiency (typically compared to coding of ST 2084, Non Constant Luminance, Y’CbCr, 4:2:0 video signals), solutions based on specific usage of VUI and SEI messages in single-layer coding solutions are presented. The document also provides conversion and coding practices for the ICTCP colour representation.

# Introduction

This document relates to high dynamic range (HDR) and wide color gamut (WCG) video distribution, using single-layer or multi-layer coding. It provides guidance for HDR and WCG video processing, using HEVC signaling, for SDR backward compatibility, display adaptation capabilities, and quality enhancement processing.

**SDR backward compatibility** relates to the ability to display a video signal on an SDR rendering device (e.g. UHD SDR display BT.2020 color primaries). It can be defined in two modes:

* In **bitstream** SDR backward compatibility, the video signal resulting from the decoding using a standard-compliant decoder (e.g. HDR Main 10 decoder) can be rendered, without adaptation, on an SDR display. The resulting SDR video can further be used to reconstruct an HDR signal by a post-decoding, possibly using side metadata.
* In **display** SDR backward compatibility, the video signal resulting from the decoding using a standard-compliant decoder (e.g. HDR Main 10 decoder) is an HDR signal (for instance, Y’CbCr 4:2:0 10-bit with ST 2084 transfer function and BT.2020 colour primaries). A post-decoding adaptation process is applied to convert this HDR signal to an SDR version that can be displayed on an SDR rendering device. The adaptation process can use side metadata to perform this conversion.

**Display adaptation** is a super-set of display SDR backward compatibility. It aims at converting a decoded HDR and WCG video signal, with a given colour volume (dynamic range and colour gamut), to a version adapted to a target rendering device of lower colour volume capabilities. For instance, it can be used to convert a non-constant luminance (NCL), Y’CbCr, 4:2:0, 10-bit, ST 2084 signal (a.k.a. HDR10) whose master was produced on a display with a given peak luminance, to a lower peak luminance capable display. This feature includes the conversion from HDR to SDR applied at the display side. Display adaptation can be driven by metadata transmitted along with the video bitstream.

**Quality enhancement processing** relates to pre-processing applied prior encoding, and to post-processing applied after decoding, that enable improving the HDR pictures quality. This topic includes in particular conversion and processing tools that provide improved coding efficiency of HDR content, compared to compression of HDR content typically represented in NCL Y’CbCr 4:2:0 video format with ST 2084 Transfer Characteristics.

The document structure is as follows. The HEVC specification and its draft new amendment include different signaling mechanisms applicable to HDR and WCG video. In particular, specific VUI syntax elements and several SEI messages are relevant for SDR backward compatibility, display adaptation, and quality enhancement processing. These signaling mechanisms are summarized in section 2. Two main coding systems, described in sections 3 and 4, are considered for providing bitstream SDR backward compatibility: single-layer coding systems with metadata (conveyed in VUI and/or SEI), and dual-layer coding system (SHVC) with an SDR base layer. Section 5 addresses the topic of display adaptation. Section 6 addresses the topic of quality enhancement processing, in particular for improved coding efficiency.

NOTE 1 – This document does not address conversion and coding processes, and corresponding post-processes, specifically related to NCL Y’CbCr 4:2:0 video with ST 2084 transfer characteristics. These aspects are specifically addressed in document [1].

# HEVC signaling mechanisms applicable to HDR and WCG video

In this section, VUI syntax elements and SEI messages specified in HEVC, applicable to HDR and WCG video and relevant to the scope of this document, are reviewed.

## VUI signaling

Rec. ITU-R BT.2100 specifies HDR-TV image parameters for use in production and international programme exchange [2]. It defines two transfer functions: Perceptual Quantization (PQ) and Hybrid Log-Gamma (HLG). RGB colour primaries are specified the same as in Rec. ITU-R BT.2020 [3]. It describes two different luminance and colour difference signal representations: Non-Constant Luminance (NCL) Y'CbCr and Constant Intensity (CI) ICTCP. HEVC specifies all the above signallings in VUI. Transfer function is indicated using transfer\_characteristics syntax element, as described in Table 2‑1. RGB colour primaries are indicated using colour\_primaries syntax element (set equal to 9 for BT.2020 primaries). Colour representation is indicated using matrix\_coeffs syntax element, as described in Table 2‑2.

Table 2‑1 – Transfer\_characteristics indication in VUI in HEVC.

|  |  |  |
| --- | --- | --- |
|  | **PQ** | **HLG** |
| **transfer\_characteristics** | 16 | 18 |

Table 2‑2 – Matrix\_coeffs indication in VUI in HEVC.

|  |  |  |
| --- | --- | --- |
|  | **NCL Y'CbCr** | **CI ICTCP** |
| **matrix\_coeffs** | 9 | 14 |

NOTE 2 – PQ is also specified in SMPTE ST 2084 and HLG is also specified in ARIB STD-B67.

## SEI messages usable for content mapping

HEVC specifies different SEI messages applicable for mapping a content from one colour volume to another one. They can be in particular used for the purpose of reshaping an input HDR signal for improved coding efficiency, or for converting (and inverse converting) an HDR signal into an SDR backward compatible version. Such content mapping SEI messages are listed in next sub-sections.

### Tone mapping information SEI message

The tone mapping information (TMI) SEI message is designed to carry one or more tone mapping curves within a coded video sequence. The tone mapping curves are used to convert the decoded image to a mapped image, for instance to target a specific display. The mapping curve is represented by a 1D LUT *LUTTM*. The curve applies to the RGB components of the decoded signal.

(2‑1)

Four methods for signaling the 1D LUT are specified: a linear model with a clip, a sigmoidal model, a piece-wise linear model, and an explicit LUT. More than one tone map can be associated with a coded video sequence through the tone mapping information SEI message identifier tags. This enables simultaneous support for multiple dynamic range targets, including targets that have greater or less dynamic range than the decoded video data.

### Colour remapping information SEI message

The colour remapping information (CRI) SEI message conveys information used to remap decoded pictures from one colour volume to another one. The syntax of CRI remapping model includes three parts: a first piece-wise linear function applied to each colour component (“Pre-LUT”), followed by a three-by-three matrix applied to the three resulting colour components, followed by a second piece-wise linear function applied to each resulting colour component (“Post-LUT”). Each one of these set of data is optional (for instance only the Pre-LUTs can apply, leading to the application of only one transfer function to each colour component of the input signal). A maximum of 33 pivot points per LUT are coded to specify the piece-wise linear functions. When the three-by-three matrix is activated, the conversion process using CRI must apply in 4:4:4. When it is not activated, logically, the Post-LUTs are not used, and the mapping process can apply in 4:2:2 or 4:2:0 chroma sampling formats.

The following equations illustrate the application of the complete CRI model to the (R,G,B) values of a color sample:

(2‑2)

(2‑3)

(2‑4)

The CRI SEI message includes a syntax element colour\_remap\_id that may be used to identify the purpose of the colour remapping information. For instance, colour\_remap\_id value may be used to indicate that the input of the remapping is the result of a first conversion process, such as conversion to Y’CbCr or GBR colour representation, or to enable cascading of different remapping processes.

# Bitstream SDR backward compatibility with single-layer coding

## Introduction

This section is focused on bitstream SDR backward compatibility support using a single-layer coding framework. Figure 3‑1 provides a simplified synoptic of single-layer distribution system offering bitstream SDR backward compatibility. The system typically uses HEVC Main 10 profile for the bitstream generation and decoding. It includes a pre-processing block, prior to encoding, that converts an input HDR signal into an SDR version. Side metadata can be generated in this step. After encoding and decoding the SDR signal, side metadata can be used in a post-processing step to reconstruct an HDR version. The decoded SDR video can be directly rendered on an SDR display without adaptation. Bitstream SDR backward compatibility can be essentially provided using two approaches: 1. by using, to generate the HDR master, an opto-electrical transfer function (OETF) offering some level of SDR backward compatibility, that is, partly similar to a BT.709 transfer function; 2. by applying an invertible HDR-to-SDR conversion process prior to the encoding, with dynamic metadata required to perform the inverse conversion after decoding.



Figure 3‑1 – Display SDR backward compatibility using single layer coding system.

[Ed. (EF): new section 3.2 could describe HLG usage for bitstream SDR BC, including usage of HDR compatibility info SEI.]

## Dynamic range adaptation with dynamic metadata signaled in SEI messages

An example of encoding process producing SDR/BT.2020 compatible HEVC bitstream is illustrated in Figure 3‑2. In this design, Dynamic range adaptation (DRA) applies three transfer functions to the Y’, Cb, and Cr components of an input HDR10 signal. These functions are derived from the analysis of input HDR signal properties and aim at producing an SDR approximation. The resulting Y’CbCr signal, having BT.709/BT.2020 transfer characteristics and BT.2020 color primaries, is then encoded, using an HEVC Main10 compliant encoder. The functions are implemented in the shape of 1D look-up-tables (*LUTDRAk*, for *k*=0, 1, 2), that directly apply to the HDR10 Y’, Cb and Cr components, in 4:2:0 format.

The decoding process is the inverse process of the described above encoding. It includes the inverse DRA process as illustrated in Figure 3‑3. After HEVC Main 10 compliant decoding, the decoded signal has BT.709/BT.2020 transfer characteristics and BT.2020 colour primaries. The post-process is used to reconstruct the HDR10 compatible signal using the inverse DRA transfer functions. These functions can be coded using three LUTs, embedded in SEI messages. In figures below, the CRI SEI is used. The conversion process directly applies to the decoded Y’CbCr 4:2:0 signal.

Parameters of DRA can be derived from HDR graded signal by using an HDR-to-SDR conversion algorithm or directly from the graded SDR signal when an SDR master is provided as input to the encoding system.

Linear RGB

HEVC main10  
encoder

HDR/WCG Encoder

Quant 10bits

DRA

Inv. ST.2084

Chroma Sampling  
4:2:0

Y’CbCr Convers.

DRA control over CRI SEI

Y’CbCR BT.2020

Figure 3‑2 – Pre-processing for producing an SDR backward compatible bitstream.

HDR/WCG Decoder

Dequant 10bits

Inverse DRA

Linear RGB

HEVC main10  
decoder

ST.2084  
EOTF

Chroma Sampling  
4:4:4

Inverse  
Y’CbCr Convers.

DRA control over CRI SEI

Y’CbCR BT.2020

Figure 3‑3 – Post-processing for guided conversion from SDR/BT.2020 to HDR/BT.2020.

**Colour remapping information SEI message**

For the DRA use case described in section 3.2, the inverse DRA functions are coded using the three Pre-LUTs of a CRI SEI message. The three-by-three matrix and the Post-LUTs are not activated. Therefore, the conversion process can directly apply to the decoded 4:2:0 Y’CbCr signal. The SDR-to-HDR conversion achieved at post-processing stage applies to each luma sample *YSDR* and each chroma samples *USDR* and *VSDR* as follows:

(3‑1)

(3‑2)

(3‑3)

NOTE 3 – The DRA and inverse DRA processes could also be based on the full CRI model, that is, the three Pre-LUTs, the intermediate three-by-three matrix, and the three Post-LUTs, to get improved performance, or wider adaptation scope. This requires that the SDR-to-HDR conversion applies in 4:4:4, and that the DRA process has been designed so that the full CRI model is invertible.

The following parameters of HEVC Main 10 bitstreams should be specified to correctly render the decoded video at displays compatible to SDR/BT.2020 representation and to conduct the HDR reconstruction to HDR10 compatible representation.

Settings in VUI:

* transfer\_characteristics 1, 6, 14 or 15 (SDR transfer function)
* colour\_primaries 9 (Rec BT.2020)
* matrix\_coeffs 9 (Rec BT.2020 non-constant luminance)
* video\_full\_range\_flag 0

Settings in CRI:

* colour\_remap\_video\_signal\_info\_present\_flag 1
* colour\_remap\_transfer\_function 16 (ST 2084)
* colour\_remap\_full\_range\_flag 0
* colour\_remap\_primaries 9 (Rec BT.2020)
* colour\_remap\_matrix\_coefficients 9 (Rec BT.2020 non-constant luminance)
* colour\_remap\_output\_bit\_depth 10

# Bitstream SDR backward compatibility with dual-layer SHVC coding

## Introduction

SHVC, the scalable form of HEVC [4][5], codes video data of different qualities into *layers*, and allows subsets of the layers of video data to be extracted and used on their own. SHVC could be used to provide a dual layer-bitstream that may be used to render an SDR video and an HDR video. The input of the coding system is an HDR content, and an SDR version of it, either provided as an input SDR master, or resulting from an automatic HDR-to-SDR conversion process such as the one mentioned in section 3.2. Different application scenarios are supported by SHVC, and the following sub-sections provide a brief overview of two applications where SHVC could be utilized for providing backward compatible solution for coding HDR video content.



Figure 4‑1 – Example of SDR backward compatible solution implemented with SHVC.

## Pre-encoding stage

In several applications, commonly in applications that have real-time workflow constraints, only the HDR master may be available from the mastering stage. In order to produce a backward compatible bitstream, pre-processing is applied on the HDR master to output an SDR video. This is also referred to as “automatic grading” of the HDR master to produce SDR video. The SDR video and the HDR master are then used to code the backward compatible dual-layer bitstream. Automatic grading may also be considered as part of the encoding stage.

In several applications, commonly in applications that do not have real-time workflow constraints, both the HDR master and SDR master may be available. The post-production stage of generating an SDR master could involve one of several processes that include, but are not limited to, tone mapping and colour grading. The resultant SDR master and the HDR master are then used to code the backward compatible dual-layer bitstream.

## Encoding and decoding stages

One typical dual-layer configuration is as follows.

The Y’CbCr 4:2:0, 10-bit HDR video is available to the SHVC encoder in the following format (signaled in enhancement layer VUI):

* transfer\_characteristics 16 (ST 2084)
* colour\_primaries 9 (Rec BT.2020)
* matrix\_coeffs 9 (Rec BT.2020 non-constant luminance)
* video\_full\_range\_flag 0

The Y’CbCr 4:2:0, 10-bit SDR video is available to the SHVC encoder in the following format (signaled in base layer VUI):

* transfer\_characteristics 1, 6, 14 or 15 (SDR transfer function)
* colour\_primaries 1 (Rec BT.709) or 9 (Rec BT.2020) depending on SRD input
* matrix\_coeffs 9 (Rec BT.709/BT.2020 non-constant luminance)
* video\_full\_range\_flag 0.

The SDR video is coded as the base layer of SHVC encoding conforming to the Main 10 profile, and the HDR master is coded as the enhancement layer conforming to the Scalable Main 10 profile. When the colour containers in which the SDR and HDR are represented are different, SHVC colour gamut scalability (CGS) tool [6] can apply to encode the content with good coding efficiency [7][8]. Even if the colour containers in which the SDR and HDR are coded are the same, the colour volume occupied by the SDR and HDR pictures is typically different. Even in such cases, the CGS tool can encode the video with good coding efficiency.

The dual-layer bitstream is then decoded using an SHVC decoder, with the output from the base layer resulting in an SDR video representation and the enhancement layer resulting in a HDR video representation.

# Display adaptation

## Introduction

Display adaptation aims at converting a decoded HDR video (typically HDR10) to a version adapted to the target rendering device. For instance, it may be used to convert an HDR10 video having a given peak luminance to a display capable of displaying a lower peak luminance. The concept is illustrated in Figure 5‑1. The conversion process can be driven by metadata produced during the mastering stage, and conveyed with the main bitstream.

[Ed. (EF): it could be mentioned here ST 2094 and its potential usage for generic display adaptation (HDR-to-HDR).]

Display SDR backward compatibility is a specific example of display adaptation, when the rendering device has only SDR display capabilities. This specific case is further described in section 5.2.



Figure 5‑1 – Illustration of the concept of display adaptation.

## Case of display SDR backward compatibility

Dynamical range conversion from HDR to SDR is an inverse problem of bitstream SDR backward compatibility studied in section 3.2. Due to invertibility of the DRA process, this system design can be straightforwardly deduced from Figure 3‑2 and Figure 3‑3 by placing a forward DRA process to the decoder side and signaling DRA parameters through SEI message such as CRI.

An encoding process producing HDR/BT.2020 compatible HEVC bitstream which includes DRA control parameters for decoder side guided conversion from HDR to SDR is illustrated in Figure 5‑2.

A corresponding decoding process which enables to conduct an optional guided mapping from HDR to SDR through forward DRA process is illustrated in Figure 5‑3. After HEVC Main 10-compliant decoding, the decoded signal has ST 2084 transfer characteristics and BT.2020 colour primaries which makes it HDR10 compatible. The post-process can be used to convert decoded HDR/BT.2020 signal to SDR/BT.2020 representation. DRA typically applies three transfer functions to the Y’, Cb, and Cr components of the decoded HDR10 signal. The resulting Y’CbCr signal has BT.709/BT.2020 transfer characteristics and BT.2020 color primaries. Parameters of DRA can be derived with method described in the section 3.2. The functions are implemented in the shape of 1D look-up-tables (*LUTDRAk*, for *k*=0, 1, 2), that directly apply to the HDR10 Y’, Cb and Cr components. The three DRA functions can be implemented using SEI messages such as CRI, as illustrated below.0

Linear RGB

HEVC main10  
encoder

HDR/WCG Encoder

Quant 10bits

DRA  
Derivation

Inv. ST.2084

Chroma Sampling  
4:2:0

Y’CbCr Convers.

CRI

Y’CbCR ST 2084 BT.2020

SDR reference

Figure 5‑2 – Example of pre-processing using CRI for backward compatible bitstream.

HDR/WCG Decoder

Dequant 10bits

DRA

Linear RGB

HEVC main10  
decoder

ST.2084  
EOTF

Chroma Sampling  
4:4:4

Inverse  
Y’CbCr Convers.

CRI

Y’CbCR ST 2084  
BT.2020

Y’CbCR BT.2020

Figure 5‑3 – Post-processing using CRI for guided conversion from HDR/BT.2020 to SDR/BT.2020.

**Using Colour remapping information SEI message**

The three DRA functions can be implemented using the three Pre-LUTs of a CRI SEI message. The three-by-three matrix and the Post-LUTs are not activated. Therefore, the conversion process can directly apply to the decoded 4:2:0 signal. The SDR-to-HDR conversion achieved at post-processing stage applies to each luma sample *YHDR* and each chroma sample *UHDR* and *VHDR* as follows:

(5‑1)

(5‑2)

(5‑3)

NOTE 4 – The full CRI model could also be considered to get improved performance, or wider adaptation scope. For instance, the three-by-three matrix, in addition to the three Post-LUTs, can be used to enable conversion from BT.2020 colour primaries to BT.709 colour primaries, when the target SDR display is only supporting BT.709 primaries. The activation of the full CRI model would require to perform prior to the application of the CRI an upsampling from 4:2:0 to 4:4:4.

The following parameters of HEVC main10 bitstreams shall be specified to correctly display video on HDR10 compatible devices and to conduct a guided mapping from SDR to HDR with CRI post-processing.

Settings in VUI:

* transfer\_characteristics 16 (ST 2084)
* colour\_primaries 9 (Rec BT.2020)
* matrix\_coeffs 9 (Rec BT.2020 non-constant luminance)
* video\_full\_range\_flag 0

Settings in CRI:

* colour\_remap\_video\_signal\_info\_present\_flag 1
* colour\_remap\_transfer\_function 1, 6, 14 or 15 (SDR transfer function)
* colour\_remap\_full\_range\_flag 0
* colour\_remap\_primaries 9 (Rec BT.2020)
* colour\_remap\_matrix\_coefficients 9 (Rec BT.2020 non-constant luminance)
* colour\_remap\_output\_bit\_depth 10

# Quality enhancement processing

## Dynamic range adjustment for improved coding efficiency

HDR and WCG video compression can be improved by adjusting the distribution of input encoder samples codewords, using DRA approach. In this case, DRA is used to reshape the input signal in order to get better compression performance. This applies for instance to HDR video represented in Y’CbCr, 10-bit, with PQ transfer characteristics and BT.2020 colour primaries (a.k.a. HDR10). Reshaping is motivated by the fact that a PQ 10-bit signal does not, in general, fully exploit the codeword range of [0,1023]. The ST 2084 transfer function covers a linear-light range from 0 to 10,000 nits that can be much larger than the actual HDR signal range. Similarly, the actual colour gamut of the HDR signal can be noticeably lower than the BT.2020 colour gamut container. In addition, when the signal is represented in limited range, the foot-room and head-room values are not exploited. DRA aims at adaptively redistribute the codewords to reduce the impacts of quantization and therefore to get improved texture sharpness and color restitution after compression.

**Encoding and decoding processes**

The encoding process using DRA is illustrated in Figure 6‑1. DRA typically applies three transfer functions to the Y’, Cb, and Cr components of the input HDR10 signal resulting in a full range reshaped signal. These functions are derived from the analysis of the signal properties and aim at better distributing the code values. The reshaped signal is then encoded, using an HEVC Main10 compliant encoder. Reshaping functions are typically implemented in the shape of 1D look-up-tables (*LUTDRAk*, for *k*=0, 1, 2), that directly apply to the HDR10 Y, Cb and Cr components.

The decoding process including the inverse DRA process is illustrated in Figure 6‑2. After HEVC Main 10-compliant decoding, the decoded signal is post-processed to generate the HDR10 signal using the inverse DRA transfer functions. These functions are coded using the three Pre-LUTs of a CRI SEI message. The three-by-three matrix and the Post-LUTs are not activated. Therefore the conversion process can directly apply to 4:2:0 signal, without any chroma subsampling.



Figure 6‑1 – Pre-processing synoptic using CRI for DRA.



Figure 6‑2 – Post-processing synoptic using CRI for DRA.

**Derivation of the reshaping parameters**

The steps for generating the DRA functions applied in the pre-processing are summarized as follows:

* Derivation of the forward DRA functions *fDRAc*, for *c*=0 (for luma), 1,2 (for chroma);
* Derivation of the inverse reshaping functions *invfDRAc*, for c=0,1,2;
* Modeling of the inverse reshaping functions *invfDRAc*, for c=0,1,2 by PWL models *Pre-LUTc*, and generation of corresponding look-up-tables *LUTDRAc*, with proper range management;
* Derivation of the inverse LUTs *invLUTDRAc* derived from *LUTDRAc*, for c=0,1,2;
* Reshaping using the forward DRA LUTs *invLUTDRAc*, for c=0,1,2;
* Coding of the PWL models of *Pre-LUTc*, for c=0,1,2.

Examples of DRA parameters derivation for purpose of HDR/WCG compression efficiency improvement are described in [9][10].

The post-processing consists in decoding the parameters of the PWL models *Pre-LUTc*, for c=0,1,2, and in performing the inverse DRA process by applying the LUTs *LUTDRAc* to the luma and chroma components.

**Full and limited range management**

DRA converts a standard range HDR10 signal into a full range reshaped signal. The conversion from limited range to full range by the inverse DRA process is directly addressed by the CRI LUTs *LUTc*, for c=0,1,2, derived from the Pre-LUTs. For 10-bit Y’CbCr signal, it is recommended to generate the LUTs as follows:

For luma: (6‑1)

For chroma: *k*=1 or 2 (6‑2)

where are the inverse of the Y, Cb, Cr DRA LUTs, respectively, generating a full range Y’CbCr signal (that is, so that ).

**VUI settings**

As the reshaped HDR signal is based on adaptive transfer functions not specified in the VUI transfer functions, it is recommended to set the VUI syntax element transfer\_characteristics to “Unspecified”. The syntax element video\_full\_range\_flag should be set to 1. The other syntax elements should not be modified compared to the settings used when DRA does not apply.

In summary, the following settings are recommended in the VUI:

* transfer\_characteristics “Unspecified”
* colour\_primaries 9 (Rec BT.2020, non constant luminance)
* matrix\_coeffs 9 (Rec BT.2020 non-constant luminance)
* video\_full\_range\_flag 1

**Using Colour remapping information SEI message**

In the CRI message, the syntax elements colour\_remap\_transfer\_function should be set to 16 (ST 2084), and colour\_remap\_full\_range\_flag should be set to 0.

In summary, the following settings are recommended in the CRI:

* colour\_remap\_video\_signal\_info\_present\_flag 1
* colour\_remap\_transfer\_function 16 (ST 2084)
* colour\_remap\_full\_range\_flag 0
* colour\_remap\_primaries 9 (Rec BT.2020)
* colour\_remap\_matrix\_coefficients 9 (Rec BT.2020 non-constant luminance)
* colour\_remap\_output\_bit\_depth 10

## ICTCP colour representation

### ICTCP property

An overview of CI *ICTCP* is given in [2][11]. Compared with NCL *Y’CbCr*, *ICTCP* provides several benefits when used with the PQ or HLG non-linearity.

* **Achromatic channel** **(Constant Luminance)**: The achromatic axis of *Y'CbCr* (*Y’* encoded in PQ or HLG) does not fully de-correlate luminance from colour. Therefore, distortions introduced into the chroma channels can propagate to luminance where they become much more noticeable. As shown in Figure 6‑3, the achromatic axis of *ICTCP* (*I*) corresponds very closely with luminance (where luminance is a weighted sum of linear-light R, G, B). This is an indicator of how well *ICTCP* separates luma from chroma information. This reduces errors that can be introduced when spatially sub-sampling the chroma components (such as the 4:2:0 widely used for compression) compared with NCL *Y’CbCr.*
* **Colour sub-sampling**: NCL *Y'CbCr* introduces distortions when chroma sub-sampling (4:2:0 or 4:2:2) applies to saturated BT.2100 colors due to *Y'CbCr*’s NCL attributes. Colour sub-sampling issue of NCL *Y'CbCr* representation has been detailed in [1]. To alleviate the problem, a closed loop conversion process, Luma Adjustment or its variation, is described in [1]. Luma Adjustment is a closed loop conversion process where the impact of chroma down‑sampling, quantization, inverse quantization, and up‑sampling, has to be accounted for during the luma conversion process. In addition to the increased complexity, the close loop nature of Luma Adjustment poses several limitations for chroma sub-sampling process [1][12][13]. The study on error robustness of Luma Adjustment is still under investigation [12][13]. *ICTCP*, as a nearly CL representation, does not produce the colour artifacts introduced by chroma subsampling, and no additional complexity is needed to perform any luma adjustment.
* **Quantization to limited bit-depth:** when measuring the worst case visual colour difference between chroma channel code values (using ∆*E*2000 distortion metric) at various luminance levels, 10-bit *ICTCP* provides an approximately 1.5 bit colour difference improvement over 10-bit *Y’CbCr*. At less than an average of 1.0 ∆*E*2000 above the visual difference threshold, use of *ICTCP* significantly decreases visible distortions thus enabling excellent colour performance with 10-bit encoding.
* **Uniformity and hue linearity:** A colour space is hue linear when the hue remains constant as saturation or intensity are changed. Hue linearity is important during any interpolation such as colour volume mapping, chroma subsampling, and blending/fading. *Y’CbCr* has large deviations that cause hue shifts with highly saturated colours. *ICTCP* was designed to minimize deviation from lines of constant hue thereby reducing hue shifts. In addition, *ICTCP* has a more uniform distribution of colours. This improves efficiency, reduces worst case quantization and interpolation errors.

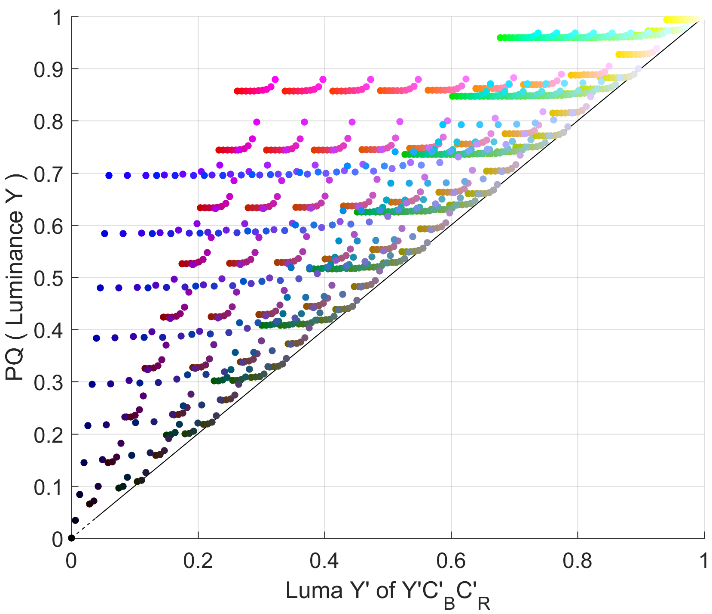
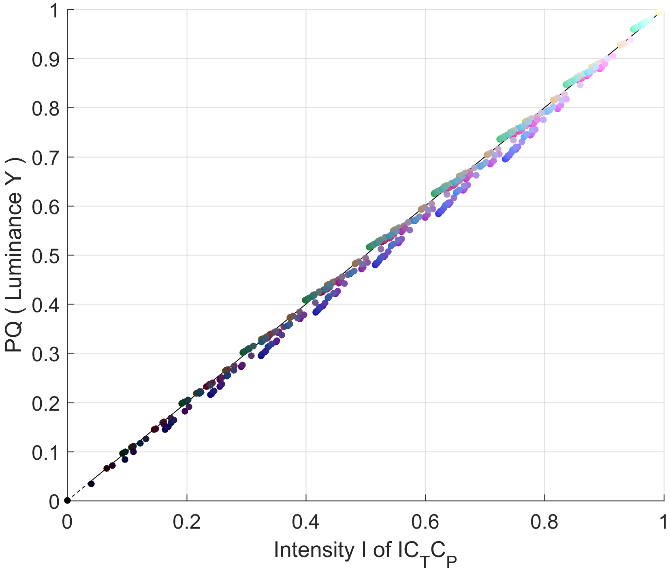


Figure 6‑3 – Luminance correlation with ICTCP and Y’CbCr colour representations.

### Guidelines for use of PQ ICTCP with HEVC or AVC

This section is to provide some guidelines for the operation of AVC or HEVC systems adapted for compressing HDR video. The described system follows the same workflow of PQ NCL Y'CbCr 4:2:0 video signals as described in [1]. The system consists of four major stages: Pre-encoding processes (Section 6.2.2.1), an Encoding process (Section 6.2.2.2), a Decoding process (Section 6.2.2.3), and Post-decoding processes (Section 6.2.2.4). These four stages are applied sequentially with the output of one stage being used as input to the next stage according to the above-mentioned order. It is assumed that both the input to and the output of the HDR System are 4:4:4, linear light, floating-point signals, in an RGB colour representation using colour primaries in accordance with BT.2020 and BT.2100. It is also assumed that encoding and decoding is performed in a 4:2:0, 10-bit representation.

NOTE 5 – The main goal of this section is to highlight the conversion and coding difference between PQ ICTCP and PQ NCL Y'CbCr signal. More details on common parts of these two systems can refer specifically in [1].

NOTE 6 – The same workflow can be used for HLG ICTCP by substituting PQ with HLG.

#### Pre-encoding process

The pre-encoding process includes the following components, as presented in Figure 6‑4:

1. a conversion component from a linear-light RGB data representation to a linear-light LMS data representation,
2. a conversion component from a linear-light LMS data representation to a non- linear-light data representation using the PQ transfer function,
3. a colour format conversion component that converts data to the Constant Intensity ICTCP representation,
4. a conversion component that converts a floating-point representation to a fixed-point representation (i.e. 10 bits), and
5. a chroma down-conversion component that converts data from 4:4:4 to 4:2:0.



Figure 6‑4 – Conventional pre-encoding process system diagram.

##### Conversion from a linear-light RGB representation to linear-light LMS

Conversion from a linear-light RGB to a linear-light LMS representation is commonly performed using a 3x3 matrix conversion process, where RGB color primaries are in accordance with BT.2020 and BT.2100.

(6‑)

##### Conversion from a linear-light LMS to a non- linear-light PQ LMS representation

Conversion from a linear-light to a non-linear light representation is performed using an inverse transfer function of PQ.

For PQ, the non linear-light representation V of a linear-light intensity signal Lo, which takes values normalized to the range [0, 1], can be computed as:

V = iTF(Lo) = ( ( c1 + c2 \* Lon ) ÷ ( 1 + c3 \* Lon ) )m (‑)

where c1, c2, c3, m, and n are constants, which are defined as follows:

c1 = c3 − c2 + 1 = 3424 ÷ 4096 = 0.835 937 5 (‑)

c2 = 2413 ÷ 128 = 18.851 562 5 (‑)

c3 = 299 ÷ 16 = 18.687 5 (‑)

m = 2523 ÷ 32 = 78.843 75 (‑)

n = 1305 ÷ 8192 = 0.159 301 757 812 5 (‑)

The peak value of 1 for Lo is ordinarily intended to correspond to an intensity level of 10 000 candelas per square metre, while the value of 0 for Lo is ordinarily intended to correspond to an intensity level of 0 candelas per square metre.

This process is applied to all L, M, and S linear-light samples, where each component is a number between 0.0 (representing no light) and 1.0 (representing 10 000 candelas per square metre). This results in their non linear-light counterparts L′, M′, and S′

as follows.

L′ = iTF( L ) (‑)

M′ = iTF( M ) (‑)

S′ = iTF( S ) (‑)

##### Colour representation conversion: L'M'S' to ICTCP

Conversion from L'M'S' to ICTCP representation is commonly performed using a 3x3 matrix conversion process.

(‑)

##### Chroma down-conversion

Converting the ICTCP video data from a 4:4:4 representation to a 4:2:0 representation follows the same process described in section 7.1.3 in [1].

##### Floating-point to fixed-point (narrow range) 10 bit conversion

Conversion from a floating-point to a fixed-point, narrow range, 10-bit representation follows the same process described in section 7.1.4 in [1].

#### Encoding process

PQ ICTCP data coming out from preprocessing step will exhibit different characteristics than PQ NCL Y'CbCr data. Study shows for current test data [14]: 1) Y’ component in Y’CbCr and I component in ICTCP have very similar compression characteristics in terms of variance; this results in similar coding bits given same luma quantizer. It suggests that techniques designed to improve coding efficiency of Y’ component (e.g., perceptual luma quantization in [1]) can be used for I component directly. 2) for colour components, CT and CP have higher variance level than Cb and Cr, thus modifications have to be applied for technologies designed to improve chroma coding efficiency, such as the adaptive chroma QP offset model in [1].

The Recommended setting for HEVC encoding is listed in Table 6**‑**1. The recommendation for AVC encoding is listed in Table 6‑2.

Table 6‑1 – Recommended settings for HEVC encoding.

|  |  |
| --- | --- |
| **Syntax element** | **Recommended value** |
| **general\_profile\_space** | 0 |
| **general\_profile\_idc** | 2 |
| **video\_full\_range\_flag** | 0 |
| **colour\_primaries** | 9 |
| **transfer\_characteristics** | 16 |
| **matrix\_coeffs** | 14 |
| **chroma\_sample\_loc\_type\_top\_field** | 2 |
| **chroma\_sample\_loc\_type\_bottom\_field** | 2 |

Table 6‑2 – Recommended settings for AVC encoding.

|  |  |
| --- | --- |
| **Syntax element** | **Recommended value** |
| **profile\_idc** | 110 |
| **video\_full\_range\_flag** | 0 |
| **colour\_primaries** | 9 |
| **transfer\_characteristics** | 16 |
| **matrix\_coefficients** | 14 |
| **chroma\_sample\_loc\_type\_top\_field** | 2 |
| **chroma\_sample\_loc\_type\_bottom\_field** | 2 |

[Ed. (PY): more details can be added later in encoding process if needed.]

#### Decoding process

When the bitstream is an HEVC bitstream the decoding process in the HEVC specification [4] is performed.

When the bitstream is an AVC bitstream the decoding process in the MPEG-4 AVC/H.264 specification [15] is performed.

#### Post-decoding process

The post-decoding stage includes the following components:

1. a chroma up-conversion component that converts data from 4:2:0 to 4:4:4,
2. a conversion component that converts a fixed-point representation, i.e. 10 bits, to a floating-point representation,
3. a colour format conversion component that converts data from the ICTCP representation back to the non linear-light L′M′S′ representation, and
4. a conversion component from the non linear-light L'M'S' data representation back to a linear-light LMS data representation.
5. a conversion component from a linear-light LMS data representation to a linear-light RGB data representation.



Figure 6‑5 – Conventional post-decoding process system diagram.

##### Conversion from a fixed-point to a floating-point representation

Conversion from a fixed-point narrow range, 10-bit representation to a floating-point, follows the same process described in section 10.1.1 in [1].

##### Chroma up-conversion

Converting the ICTCP video data from a 4:2:0 representation to a 4:4:4 representation follows the same process described in section 10.1.2 in [1].

##### Colour representation conversion: ICTCP to L′M′S ′

Conversion from the ICTCP representation back to the L′M′S′ representation can be performed using a 3x3 matrix conversion process.

(‑)

##### Conversion from a non linear-light to a linear-light representation: L′M′S′ to LMS

Conversion from a non-linear to a linear-light representation is performed using a forward transfer function.

For PQ, the linear-light intensity signal Lo can be computed from the non linear representation V, which takes values in the range [0, 1], as follows:

(‑)

where c1, c2, c3, m, and n were defined in section 6.2.2.1.2. This results in Lo taking value in the range [0, 1]. The peak value of 1 for Lo is ordinarily intended to correspond to an intensity level of 10 000 candelas per square metre, while the value of 0 for Lo is ordinarily intended to correspond to an intensity level of 0 candelas per square metre.

This process is applied to all L′, M′, and S′ non-linear representations, resulting in their linear-light counterparts L, M, and S as follows,

L = TF( L′ ) (‑)

M = TF( M′ ) (‑)

S = TF( S′ ) (‑)

where each component is a number between 0.0 (representing no light) and 1.0 (representing 10 000 candelas per square metre).

##### Colour representation conversion: LMS to RGB

Conversion from the LMS representation back to the RGB representation can be performed using a 3x3 matrix conversion process, where RGB color primaries are in accordance with BT.2020 and BT.2100 and each component, L,M,S, R, G, and B, is a number between 0.0 (representing no light) and 1.0 (representing 10 000 candelas per square metre).

(‑)

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# Abbreviations and acronyms

This document uses the following abbreviations and acronyms:

AVC Advanced Video Coding

CL Constant Luminance

DRA Dynamic Range Adaptation; DRA consists in a mapping process of a content from one colour volume to another colour volume.

EOTF Electro-Optical Transfer Function

HDR High Dynamic Range

HDR10 HDR content representation that utilizes the HEVC Main 10 codec, BT.2020 colour primaries, the  
ST 2084 transfer function (PQ), and non-constant luminance Y′CbCr encoding.

HEVC High Efficiency Video Coding

ICTCP Alternate colour space representation to Y’CbCr, specified in recommendation BT.2100.

NCL Non Constant Luminance

PQ Perceptual Quantizer. Informal naming of the SMPTE ST 2084 transfer function standard.

RGB Colour System using Red, Green, and Blue components

SDR Standard Dynamic Range

SEI Supplemental Enhancement Information

OETF Opto-Electrical Transfer Function

TF Transfer Function

VUI Video Usability Information

WCG Wide Colour Gamut

Y′CbCr Colour space representation commonly used for video/image distribution as a away of encoding RGB information. Also commonly expressed as YCbCr. Relationship between Y′CbCr and RGB is dictated by certain signal parameters, such as colour primaries, transfer characteristics, and matrix coefficients. Unlike the Y in the XYZ representation, Y′ in this representation might not be representing the same quantity, and is commonly referred to as luma.

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