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| *Title:* | **AHG14: Tone Mapping Information and Related SEIs for HDR Coding** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Proposal | | |
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# Abstract

This proposal presents several backward compatible solutions to coding HDR video, by effectively modifying the pre/post processing components of the anchor HDR video coding processing chain (essentially an HDR10 compliant system). Several dynamic range adaptation (DRA) schemes are proposed, which could be applied either to linear or non-linear light input. The usage of several SEI’s: Tone mapping information (TMI), Color remapping information (CRI), and Mastering display color volume (MDCV), for transmitting suitable metadata, is also described. Representative objective results based on quality metrics are provided at the end of the document, in both linear and nonlinear light. It is asserted that the proposed coding scheme provides superior visual quality to the HDR10 anchor, while also providing for SDR backward compatibility.

# Introduction

As part of the investigations done to leverage existing video standards for efficiently encoding HDR/WCG videos, FastVDO developed several effective approaches for HDR video coding [1]. All our methods can be implemented entirely as pre/post processing steps, and do not necessitate any normative changes to the core Main10 encode/decode processes. Moreover, the output of a Main10 decoder is an optimized SDR rendering. The HEVC standard [3] describes two different SEI messages, Tone mapping (TMI) SEI message and the Color remapping information (CRI) SEI message, for content mapping. In this proposal modification to the pre- and post-processing components of the anchor HDR video coding processing chain and details of metadata signalling using MDCV, TMI and CRI SEI are described. Our results have previously been presented at the SPIE [6]. Technicolor has kindly cross-checked our results for DRA applied to linear light input (document JCTVC-Y0045).

# System Overview

There are a variety of related, but somewhat different methods for achieving our goals. In this document, two methods are proposed for the pre/post processing step. One works in linear light, the second works in nonlinear light (in our example, in the PQ domain). Both are applied here in 4:4:4 domain, although that can also be modified.

1. **DRA on Linear Light:** The generic HDR-to-SDR conversion approach is shown in Figure 1. In this method, the DRA is performed on linear light input signal. Figure 2 describes some details of the DRA scheme as pre and post processing.

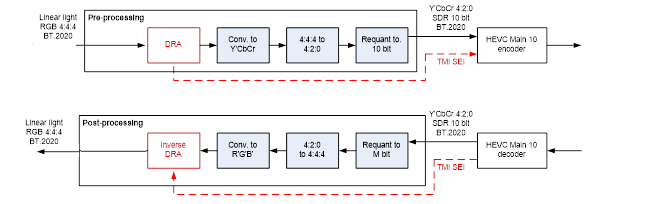
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Figure 1. Generic signal processing scheme with DRA, as pre- and post processing.

Grade HDR to SDR in 4:4:4

RGBHDR RGBSDR

Generate Data Dependent HDR to SDR Grading Function

Metadata

Figure 2. DRA scheme, which regrades HDR to SDR.

The pre-processing step involves the computation of a data dependent HDR-to-SDR grading function/process. Since the input linear light data is presented in floating point, one example DRA works in floating point as well. A base transfer function, which can be either static or adaptive, is modified depending on the statistical analysis of the linear light HDR RGB input signal. Example base transfer functions that can be used include ST-2084 (Dolby PQ), Philips TF [2], and HLG (ARIB STD-B67). The computed grading function/process is represented as a 1D LUT. The generated metadata consists of the color volume information and the 1D LUT represented using a piecewise linear function with 10 pivot points. The grading function/process is then used to grade the HDR RGB input signal to an SDR RGB signal. The SDR RGB signal is then color transformed to Y’CbCr, downsampled from 4:4:4 to 4:2:0 and encoded using HEVC reference codec (Main10 profile). The metadata is signaled using MDCV and either the TMI or CRI SEI.

***A.1) Data dependent HDR-to-SDR grading function/process:*** Figure 3 describes the technique involved in generating the grading function/process.

Piecewise

Linear Tone

Mapping

Generate

Grading

Factor

Apply adaptive OETF

Apply adaptive EOTF

Coding TF

Generate

Luminance

RGBHDR

Figure 3. Data dependent grading

***A.2) Generate Luminance:*** A luminance component (Y) is generated using either the common conversion to the Y’CbCr color space. This part is linear. All other components are nonlinear, and they can be all combined into a single function for purposes of implementation.

***A.3) Apply data adaptive OETF:*** The linear luminance (Y) input signal is converted to a perceptually uniform signal, but using a FastVDO-modified version of ST-2084 [4], herein “FVPQ”. The FVPQ function is described as:

Here, and is new parameter, indicative of the peak brightness of the data. When the parameter equal 10,000, this reduces to the usual PQ function.

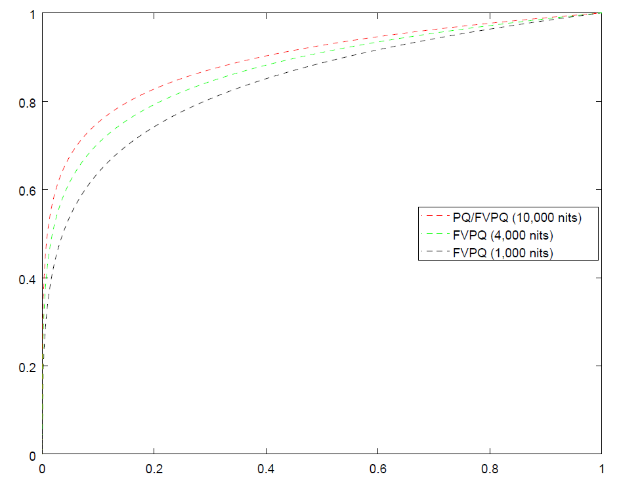
 This represents a first level of adaptivity, and is an important step in creating SDR intermediates that better capture the artistic intent of the HDR content. Since this is a tone mapping, it can be signaled using the Tone Mapping SEI, among other ways.

Figure 4. FVPQ OETF, for values of *InputPeakBrightness =* 10000, 4000, and 1000 nits (at 10K nits it coincides with the ST-2084 PQ function), as pictured from top to bottom. Note that when the input data is below 10000 nits, our TF affords more codewords at the brighter end than the standard PQ transfer function.

***A.4) Piecewise Linear Tone Mapping:*** A great variety of tone mapping schemes can be applied for HDR coding, and implemented in a variety of ways as well. In this paper, for convenience, we will only mention a piecewise linear mapping scheme. To add a modest amount of flexibility, we consider an L-piece linear model, where L >=1. For each piece the model can be represented as:

where, *k* represents the *kth* piece or bin. These equations are applied to the to generate a new signal .Let *MAX\_INPUT\_LUMA* be the maximum luminance of the input signal and *MAX\_DISPLAY\_LUMA* be the maximum luminance of the target SDR display. The coefficients *a(k), b(k)* are sequence dependent and are derived based on the distribution characteristics of the HDR input signal. As a specific example, they can be based on a histogram analysis, as follows. The input luma signal is segmented to *L* bins, and a count is kept for the number of pixels in each bin. Under an optimization process, the number of bins and their respective sizes are chosen such that the lower and mid tone levels have an improved representation compared to the unadjusted transfer function representation. Thus the parameters *a, b* are chosen for each piece such that:

where *MAX\_LUMA\_BINk* is the maximum luma value in bin *k*, and *binsizek* is the number of pixels in bin *k*.

|  |  |
| --- | --- |
|  |  |

Figure 5. Example histograms of first frame of (a) BalloonFestival, and (b) Market sequence, as example statistical basis for tone maps.

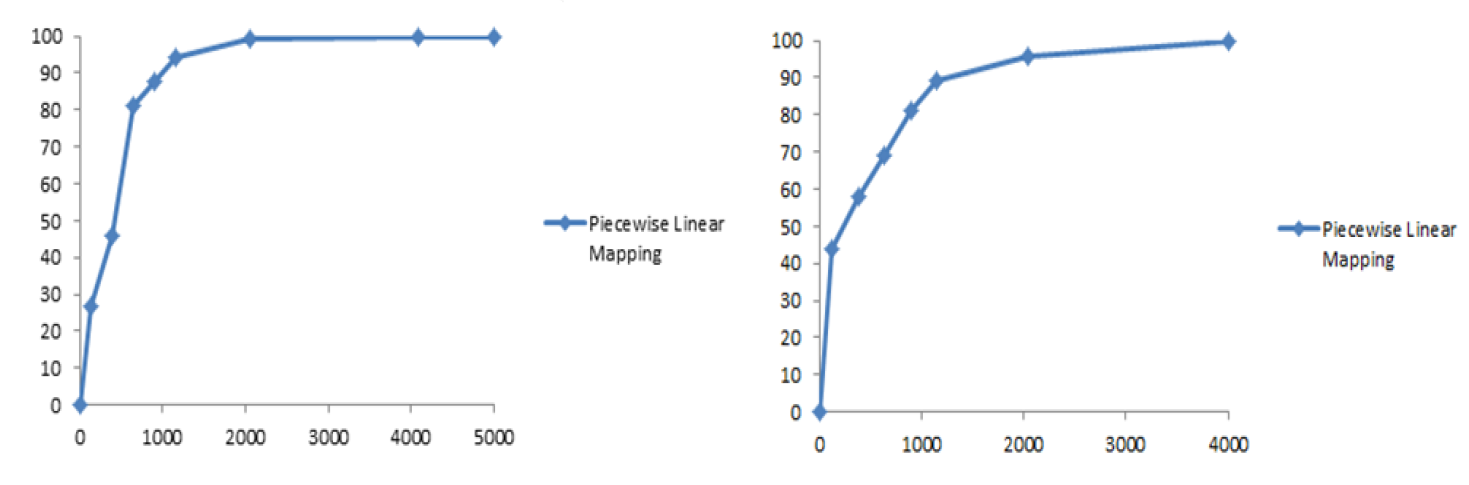


Figure 6. Example piecewise linear mappings corresponding to the statistics (histogram here) for (a) BalloonFestival, and (b) Market.

***A.5) Apply data adaptive EOTF:*** The perceptual domain signal is converted back to linear light (Y’) using the matching inverse FastVDO-modified ST-2084 OETF (FVInvPQ). The function is described as:

Here *dMax(a,b)* returns *a* if *a > b,* else *b*.

***A.6) Generate Grading Factor:*** The grading factor (actually, a function of x, y, and t) is calculated as:

This is then used to generate an intermediate signal (RGBSDR)’ = RGBHDR \* λ.

***A.7) Coding TF:*** Finally, a backward compatible SDR signal, RGBSDR, is generated by further applying a function like the ITU-R Rec. BT.2020 power-law gamma curve [5] or the ST-2084 (PQ TF).

The entire processing chain in Figure 2 can be visualized as a single tone mapping scheme.

*Post-processing:* The post-processing step in the proposed HDR coding chain is presented in Figure 7.

Regrade SDR to HDR in 4:4:4

RGBSDR RGBHDR

Generate Data Dependent SDR to HDR Regrading Function

Metadata

Figure 7. Post-Processing, which recovers HDR from SDR.

The HEVC reference codec is used to decode the bitstream and generate the reconstructed Y’CbCr 4:2:0 signal and metadata. The Y’CbCr 4:2:0 signal is then upsampled from 4:2:0 to 4:4:4 and color transformed to SDR RGB. The regrading function/process is computed using the metadata. The process is very similar to that described in Figure 2, except that the blocks are in reverse order. Finally, regrading is performed on the SDR RGB input to obtain the linear light reconstructed HDR RGB signal.

1. **DRA on nonlinear light (e.g., PQ) input:** The pre/post processing chain is detailed in Figure 8, as an example. Other nonlinearities besides PQ can also be used.



Figure 8

Thus, in our example processing chain, the input to DRA block is non-linear light RGBHDR\_PQ 4:4:4 signal that has been quantized to M bits (14 bits in this case). DRA scheme is described in Figure 9.

RGBHDR\_PQ 4:4:4 M bits RGBSDR 4:4:4 M bits

Generate Luma (YHDR\_PQ)

Piecewise Linear Tone Mapping

Generate Grading Factor

YSDR **Metadata**

Figure 9

***B.1)*** ***Generate Luma(YHDR\_PQ):*** A luma component YHDR\_PQ is generated using the common conversion to the Y’CbCr color space.

***B.2) Piecewise Linear Tone Mapping*:** Section A.4 describes the process in detail. The input HDR signal is analyzed for the generation of this function.

***B.3) Generate Grading Factor:*** The grading factor (a function of x, y, and t) is calculated as:

Finally, for each sample value X = R, G or B:

The metadata carries the to mapping information at various pivot points (32 points in this case).

At the post-processing side, the tone mapping function is applied to the SDR luma component YSDR, to derive a scaling ratio to be applied to the RGBSDR 4:4:4 M-bits samples as follows:

For each sample value X = R, G or B:

Here M is the bit-depth of DRA/inverse DRA application (corresponding to the TMI SEI message syntax element coded\_data\_bit\_depth/target\_bit\_depth). This implementation can be beneficial to limit the color hue shift resulting from the SDR-to-HDR conversion.

**Tone mapping (TMI) SEI**

The TMI SEI syntax describes five methods for signaling a custom tone mapping curve represented as a 1D LUT: a) Linear mapping with clipping; b) Sigmoidal mapping; c) User defined table mapping; d) Piecewise Linear mapping and e) Luminance dynamic range information. In this proposal the piecewise linear content mapping scheme is used.

Settings in VUI for SDR rendering:

* colour\_description\_present\_flag 1
* colour\_primaries 9 (BT.2020)
* transfer\_characteristics 1, 6, 14 or 15 (SDR transfer function)
* matrix\_coeffs 9 (BT.2020 NCL)
* video\_full\_range\_flag 0 (narrow range)

Settings in TMI for HDR reconstruction from decoded SDR:

* tone\_map\_model\_id 3 (piece-wise linear model)
* coded\_data\_bit\_depth M (typically 14 bits)
* target\_bit\_depth M (typically 14 bits)
* num\_pivots 32

**Color remapping information (CRI) SEI**

The CRI SEI syntax consists of three sequential but optional parts: a) Piecewise linear Pre-LUT function; b) 3x3 transformation matrix and c) Piecewise linear Post-LUT function. In this proposal the Post-LUT content mapping scheme is used.

Settings in VUI for SDR rendering:

* colour\_description\_present\_flag 1
* colour\_primaries 9 (if SDR target is BT.2020) or 1 (if SDR target is BT.709)
* transfer\_characteristics 1, 6, 14 or 15 (SDR transfer function)
* matrix\_coeffs 9 (BT.2020 NCL)
* video\_full\_range\_flag 0 (narrow range)

Settings in CRI for HDR reconstruction from decoded SDR:

* colour\_remap\_video\_signal\_info\_present\_flag 1
* colour\_remap\_transfer\_function 16 (BT.2100 PQ)
* colour\_remap\_full\_range\_flag 0
* colour\_remap\_primaries 9 (BT.2020)
* colour\_remap\_matrix\_coefficients 9 (BT.2020 NCL)
* colour\_remap\_output\_bit\_depth 10

**Mastering display color volume (MDCV) SEI**

The MDCV SEI syntax describes the color volume of the mastering display used for viewing while authoring the video content.

An example of the settings used in the SEI:

SEIMasteringDisplayColourVolume: 1

SEIMasteringDisplayMinLuminance: 47

SEIMasteringDisplayMaxLuminance: 40000000

SEIMasteringDisplayPrimaries: 13250,34500,7500,3000,34000,16000

SEIMasteringDisplayWhitePoint: 15635,16450

**Results**

The objective results obtained by the proposed systems are presented below. For Approach A (linear light processing) using a) TMI SEI and b) CRI SEI are shown in Table 1 and Table 2 respectively. The reference for these tests is the HDR10 anchor v3.2. Spreadsheets with the complete metrics are provided as evidence. The proposed coding scheme provides superior visual quality to the HDR10 anchor v3.2. The generated SDR YUV 4:2:0 sequences generated after pre-processing looks more natural, and closer to the original HDR video than the anchor (HDR10) generated YUV 4:2:0 videos.

Table 1: Objective Results (using TMI SEI), Approach A (Linear Light)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | X | Y | Z | XYZ | tOSNR-XYZ | DE100 | MD100 | PSNRL100 | PSNR R | PSNR G | PSNR B | PSNR-RGB |
| class A | FireEaterClip4000r1 | 69.4% | 56.7% | 186.6% | 93.1% | 124.1% | 93.3% | -31.7% | 25.2% | -71.6% | -47.3% | -71.0% | -53.33% |
|  | Market3Clip4000r2 | 51.6% | 52.4% | 43.0% | 48.6% | 24.3% | -41.0% | 0.0% | -0.5% | -46.4% | -42.2% | -55.9% | -44.41% |
|  | SunRise | 64.7% | 72.4% | 72.4% | 70.0% | 34.6% | -67.8% | -45.4% | 9.5% | -57.4% | -43.8% | -67.7% | -48.51% |
| class B | BikeSparklers cut 1 | 32.6% | 36.9% | 37.0% | 35.5% | 38.7% | 1.1% | -22.9% | 23.8% | -44.0% | -26.6% | -42.3% | -30.74% |
|  | BikeSparklers cut 2 | 27.6% | 33.4% | 31.6% | 30.6% | 34.0% | -5.6% | -30.0% | 23.7% | -36.3% | -19.0% | -30.0% | -22.53% |
|  | GarageExit | 14.4% | 19.0% | 5.4% | 12.3% | 10.1% | -21.1% | -82.4% | 10.8% | -41.2% | -30.2% | -50.0% | -34.05% |
| class C | ShowGirl2Teaser | 26.8% | 29.2% | 42.9% | 33.7% | 19.5% | -19.1% | -83.6% | 2.7% | -51.4% | -39.7% | -62.2% | -43.96% |
| class D | StEM\_MagicHour cut 1 | 6.3% | 9.7% | 13.4% | 10.5% | 9.9% | -8.1% | -80.5% | 4.3% | -63.5% | -42.9% | -42.9% | -45.50% |
|  | StEM\_MagicHour cut 2 | 7.4% | 8.8% | 10.6% | 9.2% | 8.6% | -5.7% | -40.4% | 2.3% | -72.0% | -52.1% | -24.7% | -51.13% |
|  | StEM\_MagicHour cut 3 | 8.3% | 9.6% | 12.4% | 10.7% | 11.2% | -3.4% | -25.3% | 1.6% | -64.1% | -46.8% | -30.5% | -46.94% |
|  | StEM\_WarmNight cut 1 | 9.5% | 12.1% | 10.9% | 10.8% | 10.3% | -6.4% | -35.1% | 2.2% | -69.4% | -45.8% | -65.0% | -51.11% |
|  | StEM\_WarmNight cut 2 | 7.8% | 9.0% | 17.8% | 12.4% | 15.3% | -8.7% | 0.0% | 0.7% | -78.7% | -52.8% | -65.0% | -57.58% |
| class G | BalloonFestival | 11.7% | 19.3% | 21.0% | 17.7% | 9.0% | -32.1% | 0.0% | -6.1% | -48.2% | -37.8% | -66.2% | -42.68% |
| class H | EBU\_04\_Hurdles | 13.3% | 18.0% | 2.2% | 9.9% | -4.0% | -60.1% | -47.5% | 1.0% | -55.2% | -27.2% | -52.4% | -33.88% |
|  | EBU\_06\_Start | 44.3% | 50.1% | 36.5% | 43.2% | 25.9% | -45.2% | 0.0% | 15.9% | -46.3% | -19.6% | -44.2% | -26.01% |
|  | **Overall** | 26.4% | 29.1% | 36.2% | 29.9% | 24.8% | -15.3% | -35.0% | 7.8% | -56.4% | -38.3% | -51.3% | -42.16% |

Table 2: Objective Results (using CRI SEI), Approach A (Linear light)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | X | Y | Z | XYZ | tOSNR-XYZ | DE100 | MD100 | PSNRL100 | PSNR R | PSNR G | PSNR B | PSNR-RGB |
| class A | FireEaterClip4000r1 | 51.1% | 43.3% | 107.6% | 61.8% | 75.8% | 63.0% | -32.9% | 20.3% | -70.3% | -44.8% | -69.6% | -51.05% |
|  | Market3Clip4000r2 | 42.9% | 44.1% | 31.7% | 39.0% | 18.2% | -45.0% | 0.0% | -1.6% | -43.9% | -39.3% | -53.4% | -41.67% |
|  | SunRise | 52.4% | 59.8% | 50.9% | 54.4% | 24.1% | -70.5% | -47.2% | 6.7% | -55.0% | -41.4% | -67.4% | -46.37% |
| class B | BikeSparklers cut 1 | 28.7% | 33.0% | 26.3% | 29.3% | 31.7% | -5.9% | -28.1% | 21.4% | -41.7% | -23.9% | -40.5% | -28.19% |
|  | BikeSparklers cut 2 | 24.8% | 30.6% | 22.4% | 25.8% | 28.5% | -12.0% | -28.2% | 22.1% | -34.3% | -16.6% | -28.9% | -20.36% |
|  | GarageExit | 12.5% | 17.3% | 1.4% | 9.3% | 7.1% | -25.6% | -81.9% | 10.2% | -38.2% | -27.0% | -47.1% | -30.89% |
| class C | ShowGirl2Teaser | 19.4% | 22.6% | 26.4% | 23.4% | 9.0% | -25.9% | -82.9% | 1.2% | -48.8% | -36.6% | -60.3% | -41.11% |
| class D | StEM\_MagicHour cut 1 | 3.8% | 7.8% | 6.2% | 5.9% | 5.3% | -12.8% | 0.0% | 4.0% | -60.8% | -38.9% | -40.6% | -41.87% |
|  | StEM\_MagicHour cut 2 | 5.0% | 6.9% | 4.4% | 5.0% | 4.2% | -10.2% | -40.9% | 2.4% | -68.9% | -47.4% | -23.3% | -47.11% |
|  | StEM\_MagicHour cut 3 | 5.7% | 7.5% | 5.1% | 5.7% | 5.5% | -8.2% | -19.4% | 2.0% | -60.6% | -42.6% | -29.0% | -43.13% |
|  | StEM\_WarmNight cut 1 | 6.0% | 9.0% | 3.8% | 5.8% | 5.1% | -11.8% | -34.0% | 2.1% | -66.6% | -41.4% | -62.0% | -47.16% |
|  | StEM\_WarmNight cut 2 | 3.9% | 6.8% | 6.6% | 5.7% | 7.1% | -14.0% | 0.0% | 1.0% | -76.1% | -47.8% | -61.7% | -53.05% |
| class G | BalloonFestival | 8.5% | 16.3% | 9.4% | 11.0% | 3.0% | -36.5% | 0.0% | -5.2% | -45.6% | -34.7% | -64.1% | -39.74% |
| class H | EBU\_04\_Hurdles | 11.8% | 16.6% | -0.3% | 7.9% | -4.9% | -61.0% | -54.6% | 1.3% | -54.2% | -26.0% | -51.4% | -32.68% |
|  | EBU\_06\_Start | 39.5% | 45.9% | 29.0% | 37.3% | 22.5% | -47.4% | 0.0% | 16.0% | -43.6% | -16.7% | -41.7% | -23.17% |
|  | **Overall** | 21.1% | 24.5% | 22.1% | 21.8% | 16.2% | -21.6% | -30.0% | 6.9% | -53.9% | -35.0% | -49.4% | -39.17% |

Table 2: Objective Results (using TMI SEI), Approach B (Nonlinear light, in this case PQ)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | X | Y | Z | XYZ | tOSNR-XYZ | DE100 | MD100 | PSNRL100 | PSNR R | PSNR G | PSNR B |
| class A | FireEaterClip4000r1 | 17.2% | 30.4% | 0.0% | 173.8% | 0.0% | 23.3% | -42.7% | 7.6% | -48.8% | -35.9% | -66.3% |
|  | Market3Clip4000r2 | 14.8% | 18.0% | 3.1% | 11.1% | 2.5% | -55.6% | 0.0% | 2.3% | -24.9% | -22.5% | -38.8% |
|  | SunRise | 10.8% | 18.3% | -5.4% | 6.9% | -7.7% | -78.5% | -74.9% | 5.0% | -28.6% | -13.6% | -54.7% |
| class B | BikeSparklers cut 1 | 18.4% | 24.6% | 9.1% | 16.6% | 16.1% | -31.8% | -23.6% | 22.3% | -22.3% | -2.2% | -18.4% |
|  | BikeSparklers cut 2 | 16.6% | 24.0% | 4.3% | 14.8% | 13.1% | -38.3% | -34.3% | 23.0% | -11.5% | 7.6% | -8.0% |
|  | GarageExit | 10.9% | 19.8% | -11.1% | 4.4% | -0.4% | -53.0% | -70.8% | 18.0% | -8.0% | 7.7% | -15.7% |
| class C | ShowGirl2Teaser | 28.7% | 34.0% | 49.2% | 38.2% | 44.2% | -33.3% | -75.3% | 5.6% | -35.1% | -22.0% | -60.2% |
| class D | StEM\_MagicHour cut 1 | 0.0% | 12.6% | 4.5% | 5.2% | 3.0% | -39.8% | -57.5% | 9.2% | -35.5% | -0.5% | -27.2% |
|  | StEM\_MagicHour cut 2 | 7.8% | 14.7% | 2.0% | 6.3% | 6.8% | -33.6% | -39.9% | 7.8% | -47.4% | -19.8% | -29.9% |
|  | StEM\_MagicHour cut 3 | 10.9% | 18.8% | 11.4% | 12.7% | 17.3% | -30.0% | -16.2% | 7.9% | -27.6% | -5.6% | -26.3% |
|  | StEM\_WarmNight cut 1 | 5.0% | 11.4% | 26.4% | 15.7% | 17.5% | -32.6% | -27.6% | 2.5% | -40.8% | -7.2% | -36.5% |
|  | StEM\_WarmNight cut 2 | 6.3% | 15.7% | 65.1% | 34.8% | 52.2% | -26.7% | 0.0% | 5.4% | -55.7% | -22.0% | -40.7% |
| class G | BalloonFestival | 9.2% | 18.7% | 3.5% | 9.3% | 1.1% | -48.2% | 0.0% | 11.8% | -19.8% | -4.9% | -42.2% |
| class H | EBU\_04\_Hurdles | 14.6% | 19.0% | 1.4% | 10.2% | 3.0% | -50.9% | -53.2% | 11.5% | -38.8% | -25.6% | -48.3% |
|  | EBU\_06\_Start | 33.1% | 42.1% | 14.9% | 28.4% | 18.9% | -51.6% | 0.0% | 27.3% | -21.1% | 7.3% | -19.5% |
|  | **Overall** | 13.6% | 21.5% | 11.9% | 25.9% | 12.5% | -38.7% | -34.4% | 11.1% | -31.1% | -10.6% | -35.5% |

**Conclusion**

A framework is presented for effective coding of HDR/WCG video, which can in some instances be HDR10 compliant, and provides a useful approach to backward compatibility. Several related methods are presented, each is effective in providing both coding gain, and backward compatibility, as determined by PSNR as well as informal visual inspections.

1. **References**

[1] Pankaj Topiwala, Wei Dai and Madhu Krishnan, “HDR CE5: Report of Experiment 5.3.2”, JCTVC-W0055, San Diego, Feb., 2016.

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