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| *Title:* | **AHG8: On the need of luma delta QP for BT.2100 HLG content** | | |
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# Abstract

This contribution presents an analysis on the distribution of code levels for content represented using the BT.2100 Hybrid Log-Gamma (HLG) transfer characteristics. The main purpose is to address one mandate of the AHG8 (Report development for HDR/WCG signalling, backward compatibility, and display adaptation) which requests exploration to study and evaluate experimental conditions in the context of an HLG container. Accordingly, the same experiment described in m37439 has been conducted taking into account the fundamental differences between BT.2100 Perceptual Quantiser (PQ, which was the focus for m37439) and HLG. Over sequences belonging to Class A – E, a linear relationship between the code levels associated with the BT.709 and BT.2100 HLG containers is reported. This result suggests that no significant redistribution of code levels between bright and dark image areas is observed when a given content is represented in these two containers. Therefore, the luma delta QP devised in m37439 (and also included in JCTVC-Z1017) does not seem to be necessary when coding HLG material. This claim is also confirmed by coding experiments where average BD-rate losses of 4% for luma and 10% for chroma are reported when the anchor is BT.709 compressed content. These coding results suggest that no particular trend or correction in the bitrate distribution should be expected when a BT.709-optimised codec compresses HLG material.

# Introduction

At the 6th JVET meeting in Hobart, Document JVET-F0094 presented a set of high dynamic range sequences graded using the BT.2100 Hybrid Log-Gamma (HLG) transfer characteristics. This material was submitted for inclusion in the test set to be used for the Call for Proposals (CfP) following the joint call for evidence on video compression with capability beyond HEVC. The main reason for this request was to emphasise the need of compression technology optimised for HDR content graded according to the HLG transfer characteristics. The material was viewed during the meeting and discussed during the JVET BoG on extended colour volume material (report included in JVET-F0107). Participants expressed general interest in having these additional clips in the JVET test material for the CfP and asked additional questions related to the distribution of code levels associated with the HLG characteristics. In particular, it was asked whether luminance QP adaptation, as applied for BT.2100 PQ material and described in JCTVC-Z1017, is also needed for HLG graded content.

For content in a BT.2100 PQ container, luminance QP adaptation (also denoted as luma delta QP) was devised to compensate the observed redistribution of code levels between bright and dark image areas associated with this transfer characteristics. MPEG Document m37439 reports a thorough analysis of this code level redistribution which was made to address the following fundamental question related to compression of HDR material: “*If a video codec introduces quantization noise with a level q in a BT.709/BT.1886 container, then what is the equivalent quantization noise in a BT.2020/ST-2084 container?*” To address this question an experiment was made whereby BT.709 sequences were converted to a BT.2100 PQ container. Over all pixels of the luminance component, a scatter plot between the code levels in the BT.709 and BT.2100 PQ representation revealed that a nonlinear relationship between each code level exists. In particular, a third order polynomial model was found to accurately fit the data. Using this cubic model, it was possible to quantify the amount of variation for each code level in the two containers. Figure 1 reports for the reader’s convenience Figures 2 and 5 from m37439 which depict the aforementioned nonlinear relationship between code levels (a) and associated variation (b). As may be noted, the variation is dependent on the level of brightness with low lights having almost a one-to-one mapping while highlights be in the order of one to four, i.e. a code level variation of ±1 in the BT.2100 PQ container corresponds to a variation of ±4 in the BT.709 container. Document m37439 also verified this nonlinear code level distribution for all sequences belonging to Class A, B, C, D, and E of the JCT-VC test material and concluded that if an HEVC codec distributes the noise independently of the luminance level in the BT.2100 PQ container, then it will introduce noise that is four times larger than its BT.709 counterpart in the highlights. To compensate for this code level redistribution, m37439 proposes to apply an offset to the Quantisation Parameter (QP) which depends on the average luminance value of the associated coding tree unit. The final values for the offset have been tuned from visual inspection during the activities of the MPEG AHG on HDR and WCG and have been included in technical report JCTVC-Z1017.

Chrominance component is also considered in m37439 where the authors found a nonlinear relationship between the code levels for Cb and Cr components in the two containers. A more accurate inspection of the data revealed that this relationship can be considered linear for given ranges of luminance values. These findings led to a corrective offset to be applied to the QP for Cb and Cr as a function of the corresponding QP for luminance component. However, this correction offset, has not been included in JCTVC-Z1017.

This contribution reports the results of the same experiment described in m37439 performed considering the BT.2100 HLG transfer characteristics. Given that HLG specifies a scene-referred system, the workflow described in m37439 has been modified to take into account this fundamental difference and a new content adaptation step has been introduced to map BT.709 content into a BT.2100 HLG container. The results obtained can provide some guidelines for the third mandate of the JCT-VC AHG8, i.e. “Study and propose test conditions for associated experiments” in the context of coding of HLG material.

The remainder of this contribution is organised as follows: Section 2 describes the processing chain associated with the conversion from BT.709 to BT.2100 HLG container with details on the mapping of the SDR regime into an HDR container. Section 3 analyses and discusses the obtained results in light of answering to the question on whether or not a luma delta QP tool should be also devised for BT.2100 HLG. Coding experiments performed over the content in both containers will be also presented and discussed. Finally, Section 4 summarises the main outcomes of the study.

 

**(a) (b)**

Figure 1: Nonlinear relationship between code levels in the BT.2100 PQ and BT.709 containers (a) and (b) associated variation using a cubic model to fit the data (from Figure 2 and 5 of m37439).

# Workflow and experimental setup

Given the widespread presence of SDR material in video coding applications, conventional encoders have been optimised for that type of content. However, the introduction of new transfer characteristics to improve the colour representation using higher dynamic range poses new challenges in the design of the optimal encoding settings for HDR material. One way to address this design would consist in quantifying how code levels associated with SDR content are mapped into HDR containers. This approach has been proposed in m37439 where BT.2100 PQ is considered as HDR container. In this section the same approach is followed for a BT.2100 HLG container. Accordingly, the workflow described in Figure 1 of m37439 is hence adapted to consider the scene-referred nature of HLG. In the following the overall workflow is described first and then details on the mapping of SDR to an HLG container are provided.

## Conversion process

Figure 2 depicts the conversion process to map a BT.709 video in a BT.2100 HLG container. Compared to Figure 1 of m37439, one can easily recognise three main differences:

* Conversion between BT.709 and BT.2020 primaries shifted before application of HLG OETF,
* Introduction of a new block labelled as “Display to scene linear light mapping”,
* Application of the BT.2100 HLG Opto-Electronic Transfer Function (OETF) in lieu of the BT.2100 PQ Electro-Optical Transfer Function (EOTF).

The first difference is introduced because the SDR to BT.2100 HLG mapping module assumes the signal in BT.2020 colour primaries. The second item in the previous list refers to the essential difference between a display-referred and scene-referred system. In fact, after the system gamma of 2.4 is inverted by the BT.1886 EOTF the obtained RGB components represent *display* linear light. In the workflow used in m37439, the BT.2100 PQ transfer characteristics could have been applied directly to these components since PQ describes a display-referred system, i.e. where each pixel represents the light emitted by the mastering display. Conversely, for a scene-referred system such as HLG, display linear light should be firstly remapped back to scene linear light so that the BT.2100 HLG OETF can correctly be applied. Omitting this latter conversion would mean that 100% of the standard dynamic range is mapped to 100% of HLG dynamic range and this will produce images which are too bright. In other words, SDR material should not be displayed at 100% HLG’s brightness. Finally, the third item in the list above refers to application of the HLG OETF given that the output of the SDR to BT.2100 HLG mapping module refers to scene liner light. The remaining processing modules in Figure 2 are the same as those described in the MPEG Call for Evidence (CfE) for HDR and WCG video coding [1] while the module labelled as “BT.1886 EOTF” implements the conversion of BT.709 scene linear light using peak luminance of 100 cd/m2 and system gamma equal to 2.4. The following subsection will provide more details on the mapping of BT.709 content in a BT.2100 HLG container.



Figure 2: Conversion process followed to map a BT.709 content into a BT.2100 HLG container.

## Mapping of SDR content into a BT.2100 HLG container

As previously mentioned, before applying the BT.2100 HLG OETF the display linear light signal needs to be mapped to scene linear light. This process is designed to ensure that the final BT.709 content mapped onto an HDR container and displayed on an HDR monitor looks as close as possible to the same BT.709 material shown on an SDR reference display.

Accordingly, the display linear light is scaled to ensure that 100% of the SDR signal is mapped to the HLG “Graphics White” reference of 75% HLG signal as recommended in [2]. The overall mapping process is depicted in Figure 3 and the parameter values associated with this mapping are still topic of discussion in ITU-R WP6C. The system gamma to be used in the HLG inverse OOTF is given by the formula in Note 5e of [3]:

γ = 1.2 + 0.42 × Log10( *Lw*/1000 ),

where *Lw* denotes the display peak luminance. As specified in [3], assuming a display peak luminance (*Lw*) of 1000 cd/m2, the resulting system gamma is 1.2. For each *scene referred* colour component *RS*, *BS*, *GS*, the inverse OOTF is given by the following equations:

,

where *RD*, *GD*, *BD* and *YD* denote the *display referred* colour and luminance components. For the luminance component the following gamma-based relationship between scene and display referred luminance is assumed:

.

The multiplication factor *M* for the dynamic range adjustment module depicted in Figure 4 is given by:

.

Using a system gamma of 1.2 yields *M* = 0.203.

In addition to the processing depicted in Figure 3 and Figure 4, a small gamma adjustment may then optionally be applied to the luminance component, to compensate for the subjective change in appearance of the SDR signal arising from a simple linear scaling of the SDR displayed light signal. Moreover, the process of inverting the HLG OOTF may be simplified by using a nominal peak luminance of 392 cd/m2: this allows to map 100 cd/m2 of an SDR signal into the 75% HLG without scaling and then applying the aforementioned the system gamma correction. Given this peak luminance, the associated system gamma computed from the formula in Note 5e of [3] is equal to 1.03. The value for this system gamma is close to unity which leads to approximate the inverse OOTF by simply inverting the gamma on the RGB components separately. Given that the value for *γ* in BT.2100 HLG was derived from experiments over HDR material and not SDR content mapped into an HDR container, a value of 1.04 has been used since this provided better subjective results. With this value for *γ*, the multiplication factor *M* for the scaling equals 0.2513. The simplified scheme is depicted in Figure 5.



Figure 3: Overall block schema for the display to scene linear light mapping.



Figure 4: Scaling performed in the dynamic range adjustment module to map 100% SDR into 75% of HLG.



Figure 5: Simplification of the scheme in Figure 3 when a peak luminance of 392 cd/m2 is chosen in the HLG inverse OOTF and the inverse OOTF is not applied to the luminance component.

# Analysis of the results

This section presents the results obtained for the conversion process described in Section 2 whereby the JCT-VC test sequences have been used as BT.709 content. The results will be discussed to address the following three main points:

* Whether a remapping of BT.709 material into a BT.2100 HLG container leads to a particular code level redistribution for luma and/or chroma as observed in m37439 for a BT.2100 PQ transfer characteristics,
* Whether this redistribution is constant or a function of particular signal features (e.g. luminance level in the HDR container),
* Whether the coding performance and visual quality is significantly affected when a BT.709-optimised codec is used over HDR material.

In the following, the experimental conditions are presented first followed by the analysis and discussion of results.

## Experimental conditions

The JCT-VC test sequences described in JCTVC-L1100 and belonging to classes A-E have been used in the experiments. This gives a total of twenty clips which span a wide range of spatial and temporal features along with being representative of broadcasting and conversational video coding applications. The majority of these sequences have 8 bits per pixel and therefore they have been expanded to 10 bits per pixel by simply shifting towards the left each pixel value by two bits.

After the conversion depicted in Figure 2 is completed, the obtained content was encoded using the JCT-VC common test conditions as per JCTVC-L1100.

## Code level relationship between BT.709 and BT.2100 HLG

As in Document m37439, also in this contribution the scatter plots between the code levels associated with BT.709 and BT.2100 HLG content are shown to appreciate how the data are distributed between the two containers. Given the two methods described for the SDR mapping in an HLG container, the results will be presented for both techniques. More precisely, the data associated with the conversion depicted in Figure 4 will be hereafter denoted as *full conversion* while *simplified conversion* will refer to the scheme in Figure 5. Accordingly, Figure 6 depicts the scatter plot for the luminance component of the BQSquare sequence. As may be noted the content spans approximatively the same range of code levels for both containers. A little thought will convince the reader that this should be expected given that both BT.709 and BT.2100 HLG describe a scene referred system which is not tied to a particular range of code levels for the display (e.g. [0, 10000] cd/m2 as in BT.2100 PQ). From the scatter plot in Figure 6 it may also be noted that there is a linear relationship between the code levels of both containers. Moreover, this linear relationship is reflected in both SDR to HLG conversion methods introduced above. Therefore, from the point of view of code level distribution the two techniques provide the same quantitative result. Accordingly, a linear, straight line model can be assumed and fitted using linear regression. The obtained equations pictured in the two subfigures correspond to:

 (11)

 (22)

The slope of the straight lines in (1) and (2) is the derivative which quantifies how much a perturbation in the code levels for BT.2100 HLG translates in the perturbation of code levels for BT.709. For BQSquare, the gain factor between the two containers is 1.5 (1.2 for the simplified approach) depending on which conversion is adopted. These values would suggest that the same level of quantisation leads to the same bitrate profile in both containers. In fact, by using the relationship between QP and quantisation step Δ for the uniform quantiser specified in HEVC:

 (33),

one can easily realise that the difference between the QP in BT.709 (QP709) and the one for BT.2100 (QP2100) can be expressed as:

, (44).

The ratio Δ709/Δ2100 in (4) represents the variation of the code level between the two containers which has been quantified to be around 1.5 (1.2). Therefore for BQSquare the difference QP709 – QP2100 equates to 3.52 (1.58) which is independent from the luminance level in the BT.2100 HLG container.

By repeating the same exercise over all tested material, the scatter plot in Figure 7 is obtained. Due to the large amount of data involved in the computation of this scatter plot, which led to out of memory exceptions in the used data processor software, an intermediate data pooling was performed as follows. For each sequence the average frame for the luminance component is firstly obtained by averaging along the temporal dimension all pixel values. All average frames are then converted into a 1D vector of length *W* × *H* where *W* and *H* denote the picture width and height, respectively. All 1D vectors corresponding to each sequence are then concatenated together to obtain the final scatter plot. From Figure 7 the same linear relationship observed for BQSquare may also be noted with a slope of the linear model equal to 1.3 (1.1), which leads to a difference QP709 – QP2100 equal to 2.3 (0.8). As already noted, this difference is independent of the particular luminance value assumed in the BT.2100 HLG container. Therefore, a difference in the order of one or two QP levels would only results in a slight variation of the bitrate but no variation in the bitrate distribution should be expected. In other words, an encoder optimised for BT.709 material is expected to perform equally over content in the BT.2100 HLG container.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 6: Code level distribution for the luminance component of BQSquare.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 7: Code level distribution for the luminance component of all tested sequences.

The code level distribution for chroma components Cb and Cr is now discussed by inspecting the scatter plots in Figure 8-Figure 11. As for the luminance component, the same pooling as described above has been also applied here. Both for BQSquare and all tested sequences a linear relationship can be observed between the code levels over the two chroma components and the two containers. Differently from m37439, this relationship is not piecewise linear; the linear models for both Cb and Cr have slopes not close to unity. Assuming the fitting from the data associated with the simplified conversion, these slope values lead to a difference in the QP for BT.709 and BT.2100 of about 3 and 7 for Cb and Cr, respectively. As explained in m37439, this difference can be expressed as the chroma QP offset to be added to the luminance QP when coding a given sequence in the BT.2100 HLG container. Therefore, for the considered test material, the following values for the pps\_cb\_qp\_offset and pps\_cr\_qp\_offset should be used when coding BT.2100 HLG material:

(QPCb709 – QPCb2100) ≈ 3 → pps\_cb\_qp\_offset = –3

(QPCr709 – QPCr2100) ≈ 7 → pps\_cr\_qp\_offset = –7

it should be noted that these offset values are static and used to compensate a potential bit shift between luma and chroma components which can also be tackled with a different weighting of the distortion or Lagrangian multipliers for Cb and Cr in the coding mode selection.

The analysis of the scatter plots for all three colour components presented in this section allows to elaborate on the first two items listed at the beginning of Section 3. In particular:

* The scatter plots in Figure 6-Figure 11 indicate that there is no particular code level redistribution when a BT.709 sequence is converted to a BT.2100 HLG container. For the chroma components an offset may be used to compensate the different scale between the code levels,
* Still from the reported scatter plots, there is no particular dependency of the code level distribution with respect to any signal feature. In fact, even the offsets observed for the chroma components are static and not depending on the luminance value in the BT.2100 HLG container.

The third item of the list in Section 3 will be addressed in the next subsection where results for coding experiments are presented and discussed. Here, it is important to remark that the experiments discussed in this section were only conducted to address one of the mandates of AHG8, i.e. which coding conditions should be used for HLG material and whether BT.2100 HLG content requires a luma delta QP tool to *compensate* any intrinsic code level redistribution associated with this transfer characteristics. The obtained results reveal that, particularly for the luminance component, there is no need of such tool. The caveat here is that this result should not prevent any encoder designer to take advantage by luminance based adaptive quantisation. As in the SDR case, this type of quantisation can improve the perceived quality of HDR content.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 8: Code level distribution for the Cb component for BQSquare sequence.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 9: Code level distribution for the Cr component for BQSquare sequence.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 10: Code level distribution for the Cb component for all tested sequences.

|  |  |
| --- | --- |
| *Full conversion* | *Simplified conversion* |

Figure 11: Code level distribution for the Cr component for all tested sequences.

## Coding experiments

This section presents the results for the coding experiments performed over the selected test material and using the JCT-VC CTC with random access and low delay configurations and the HEVC Main10 profile. In particular, the content is encoded twice according to the following:

* HEVC compression is applied over the BT.709 material and the obtained decoded sequences are converted to the BT.2100 HLG container using the workflow in Figure 2. This setup will be hereafter denoted as ***code-and-convert***.
* The test material is firstly converted into the BT.2100 HLG container and then compressed. In this setup the pps\_cb\_qp\_offset and pps\_cr\_qp\_offset are set to -3 and -7, respectively. This setup will be hereafter denoted as ***convert-and-code***.

The BD-rates are computed using the data from code-and-convert as anchors whereby the PSNR values are computed according to what depicted in Figure 12. The BD-rate results are listed in Table 1. An average BD-rate loss of 4.1 and 3.8 may be observed on the luma component for random access and low delay configurations, respectively. These losses are due to the joint effect of the conversion process (with upsampling and then downsampling) and bitrate rate re-distribution between luma and chroma given the used QP offsets. If no QP offset is used an average luma BD-rate gains of 1.6 and 0.6 are recorded for Random Access and Low Delay, respectively. However, in this case more substantial losses were observed for the chroma component which anyway could not be confirmed during visual inspection of the content. For the chroma component, average losses are in the range of [6.0 – 12.6] as may be noted from Table 1. These values are in line with the findings of m37439. From the reported results it seems that a reasonable coding performance can be obtained by using the same bitrate profile for luma and a static, content independent, offset to adjust the bit distribution between luma and chroma. Therefore, coming back to the third point of the list at the beginning of Section 3, it does not seem that particular, ad-hoc techniques are needed to compress BT.2100 HLG material with a BT.709-optimised codec. Like already said, the results and conclusions drawn here should not discourage any encoder designer to improve the coding performance for BT.2100 HLG coding but rather just indicate that no particular and content dependent bit redistribution should be expected and addressed.



Figure 12: General setup for encoding experiments.

Table 1: BD-rate values when the anchor is the code-and-convert setup.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Random Access Main10** | | | **Low delay B Main10** | | |
|  | Y | U | V | Y | U | V |
| Class A | 3.6% | 11.5% | 33.2% | 3.4% | 15.2% | 28.9% |
| Class B | 3.4% | 10.2% | -6.6% | 2.8% | 11.0% | -4.5% |
| Class C | 2.4% | 21.1% | 7.7% | 2.3% | 21.2% | 8.7% |
| Class D | 5.7% | 14.5% | 7.3% | 4.9% | 14.4% | 9.6% |
| Class E | 5.9% | 2.5% | 3.7% | 7.2% | 7.8% | 15.4% |
| **Overall** | 4.1% | 12.3% | 8.6% | 3.8% | 12.6% | 6.0% |

# Summary

This contribution has presented an analysis of the code level distribution for BT.2100 HLG content. The analysis was conducted to address one mandate of AHG8, particularly on whether also HLG material requires an adaptive quantisation tool such as the luma delta QP devised for BT.2100 PQ material. The approach proposed in Document m37439 was followed and the workflow adapted to tackle the fundamental differences between scene referred and display referred signals. Accordingly, the BT.709 JCT-VC test material has been mapped into a BT.2100 HLG container and compressed using the Main10 profile of HEVC. From the obtained data the following conclusions can be drawn:

* BT.2100 HLG does not provide any particular redistribution of the code levels when BT.709 content is mapped into this container. Therefore, a perturbation of ±*δ* in the HLG domain translates in the same amount in the BT.709 container and this is independent from any signal features as instead observed for BT.2100 PQ content in m37439,
* For the chroma components, a QP offset between luma and chroma may be necessary to have a bit distribution closer to the one associated with BT.709 coding. This offset is found to be static and may also be delegated in particular implementations to the rate distortion optimisation phase,
* No significant and unexpected coding performance penalties are observed when BT.2100 HLG content is compressed using a codec which is optimised for BT.709 material.

The whole point of the analysis presented was to explore whether some particular tool such as luma delta QP is needed also for BT.2100 HLG material. Experimental results suggest that is not the case. However, these conclusions should not be read as if for BT.2100 HLG material one cannot improve any further the encoding process. On the contrary, encoding can still take advantage by tools such as luma adaptive quantisation, ad-hoc scaling lists, etc. but this is outside the scope of standardisation activities and is left to the encoder designers’ expertise.

# References

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