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| *Title:* | Some considerations on hue shifts observed in HLG backward compatible video | | |
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# Abstract

This document reports on the initial analysis conducted by the BBC in response to the hue shifts reported by ARRIS Group, Inc. in contribution m37543. In their document, ARRIS have reported seeing hue shifts when viewing the HDR video on a legacy SDR screen. This contribution briefly outlines the BBC tests to recreate the observations, and also some further analysis of hue shift occurring in a purely SDR workflow.

# Introduction

Core Experiment 7(CE7, N15800) investigates the generation of anchors using the Hybrid Log-Gamma (HLG) technology firstly presented in m36249. HLG defines a scene-referred HDR system whose Opto‑Electronic Transfer Function (OETF) is defined in the ARIB STD-B67 specification. The Hybrid Log Gamma (HLG) Transfer Function (TF), or OETF, is designed to possibly provide backward compatibility with the “legacy” SDR systems. Such backward compatibility is intended for compatibility with existing SDR production infrastructure and for compatible distribution. At this stage, in our work, the “legacy” system is taken to be the SDR systems not needing color gamut conversion (i.e., for example, not needing BT 2020 to BT 709 color gamut conversion) but needing only the dynamic range conversion.

In the SDR backward compatibility experiment ARRIS conducted (see m37543 or W0035), they provided the video to an SDR TV display as well as to a SIM2 HDR TV. ARRIS observed, in general, the video on the SDR TV looks washed out and there is significant change in the color hue in comparison to that in the original video. ARRIS observed that the inclusion of compression did not seem to affect the hue of the video, so the observations do not seem to be associated with compression artefacts.

ARRIS also observed, the amount and the direction of the shift in hue seems to be also a function of the brightness of the object. The part that is even more noticeable is that if an object moves from a less bright area to brighter area, the hue changes quite noticeably. ARRIS have an internal video consisting of racing cars. The original color of the cars is orange where the RGB values are approximately in the ratio of 12:4:1 in BT.2020.

ARRIS observed, that as the cars move from brighter to less bright areas the color shifts from yellow-orange to orange when the (uncompressed BT.709) HLG is viewed on the SDR TV. As this shift is observed within the same video sequence, ARRIS believe it does not seem to be associated with any internal processing a TV might be doing. Additional tests were also conducted by ARRIS using synthetic EXR images.

This report attempts to recreate the experiments conducted by ARRIS and also provide some supporting evidence for the observations. As a result of this analysis we conclude that the effects seen by ARRIS are accurate, and not the result of any processing issues. However, it seems that these effects primarily illustrate the limitations of SDR video in general rather than a lack of compatibility of the HLG signal with SDR displays. It is undoubtedly correct that HDR systems can provide higher quality images, including colorimetric aspects, than conventional SDR TV; if this were not the case then there would be little point in HDR technology. So, directly comparing an HDR image with an SDR equivalent merely indicates the difference in capability of the two systems. This is not an appropriate comparison from which to make inferences about the quality of compatible images. Instead the compatible SDR image should be compared to the image that would have been produced had an SDR system been used. The analysis here presents such a comparison and demonstrates that the effects found by ARRIS are a result of the limitations of SDR systems in general, and are not specifically related to the quality of the HLG compatible image.

# Source Content Generation

ARRIS noted that an Orange shade with an RGB ratio of 105:18:3 (in Linear BT.709 Colour Space), produces the most noticeable hue shift for the SDR compatible image.

To simulate the affect, a test image was created consisting of 10 stripes, with varying intensities, but with the same ratio of RGB of 105:18:3. The colours were transformed to a BT.2020 colour space, through the XYZ colour space, assuming a D65 white point, prior to any subsequent processing. The values for the stripes are tabulated below in Table 1. In the BT. 2020 colour space the corresponding ratio of the RGB components is approximately 12:4:1.

Table 1: RGB values for test stripes.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 709 | | | XYZ | | | 2020 | | |
| R | G | B | X | Y | Z | R | G | B |
| 0.1 | 0.017143 | 0.002857 | 0.047885 | 0.03373 | 0.006692 | 0.068509 | 0.022706 | 0.005707 |
| 0.2 | 0.034286 | 0.005714 | 0.09577 | 0.06746 | 0.013384 | 0.137018 | 0.045411 | 0.011414 |
| 0.3 | 0.051429 | 0.008571 | 0.143654 | 0.101191 | 0.020077 | 0.205527 | 0.068117 | 0.01712 |
| 0.4 | 0.068571 | 0.011429 | 0.191539 | 0.134921 | 0.026769 | 0.274036 | 0.090823 | 0.022827 |
| 0.5 | 0.085714 | 0.014286 | 0.239424 | 0.168651 | 0.033461 | 0.342545 | 0.113529 | 0.028534 |
| 0.6 | 0.102857 | 0.017143 | 0.287309 | 0.202381 | 0.040153 | 0.411054 | 0.136234 | 0.034241 |
| 0.7 | 0.12 | 0.02 | 0.335193 | 0.236111 | 0.046846 | 0.479563 | 0.15894 | 0.039948 |
| 0.8 | 0.137143 | 0.022857 | 0.383078 | 0.269842 | 0.053538 | 0.548072 | 0.181646 | 0.045654 |
| 0.9 | 0.154286 | 0.025714 | 0.430963 | 0.303572 | 0.06023 | 0.616581 | 0.204352 | 0.051361 |
| 1 | 0.171429 | 0.028571 | 0.478848 | 0.337302 | 0.066922 | 0.68509 | 0.227057 | 0.057068 |

The image below in Figure 1 is a graphical representation of the test image. The colours are unlikely to be rendered correctly and should only be used for illustration purposes.

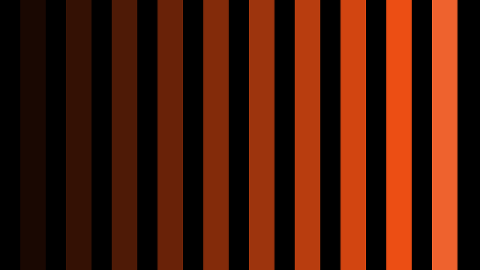


Figure 1: Test Colours (Illustrative only).

# Test Setup – Direct HDR and Compatible SDR Comparisons

The OpenEXR test image in Figure 1 was processed through internal BBC Tools for applying the OETF and followed by the EOTF options for HDR and SDR. The conversion to YCbCr 4:2:0 was not performed for this test. The reasoning for this was to avoid any clipping that may be introduced by the conversion to YCbCr colour space. Replicating the work with HDRTools is currently in progress and additional configuration will be made available in the due course.

The workflow is summarised in Figure 2. Note that the processing chain is entirely within a BT.2020 colour space.



Figure 2: Test Workflow.

The comparison for the SDR compatible image and the HDR images were made on the SIM2. Comparing the 3 versions of the HDR image at 4000 cd/m2, 2000 cd/m2 and 1000 cd/m2, very little to no hue shift was observed. When the HDR image was directly compared to the SDR compatible image, the observations from ARRIS were confirmed in the BBC setup, i.e. the Deep Orange in the HDR images does shift to Yellow-Orange.

It should be noted however, direct comparisons of HDR and SDR is very difficult, as by its nature, HDR is far superior to SDR. Colours that represent well under different intensities in HDR, may represent quite poorly under similar conditions with SDR. A more suitable comparison is to compare the compatible SDR with images obtained using a legacy SDR. To address this, the BBC extended the tests to include legacy workflows as explained in the following section.

# Test Setup – Legacy SDR and Compatible SDR Comparisons

In this extended workflow depicted in Figure 3, additional transfer functions were included in the comparisons. This allowed comparison of the compatible HLG signal with an equivalent signal from an SDR workflow.

The OETF applied to both the HDR and SDR images were matched for the low and mid tones. This implies that highlights will be more compressed, or clipped, in the SDR images compared to the HDR images. Such compression is both necessary and ubiquitous in SDR images because of their limited dynamic range. Due to the different normalisation for the linear scene light in HLG (normalised to the range [0:12]) and for SDR (normalised to the range [0:1]), input images were scaled by a factor of 3 for SDR images to achieve this match. To match the extended range for the HDR images to the legacy SDR, the input values were scaled by a factor of 3. This may cause clipping in certain patches, which is an expected outcome for SDR, as it cannot support the large dynamic supported with HDR.

A knee function was selected to match the SDR OETF to a breakpoint of ~70% of the input, extending the range to 300%. The SDR OETF with this knee supported the same peak signal level at the HLG HDR OETF. This was done to ensure the fairest possible comparison between HDR and SDR workflows.



Figure 3: Enhanced Workflow.

The BBC observed that the legacy SDR systems show similar amount of hue distortions compared to that seen on the compatible SDR image.

# Quantifying the Distortions

Comparing HDR and SDR images is not well established as there does not seem to a metric by which they can be suitably compared. Visual comparisons are the most suitable, nonetheless, the below is a tabulated form of the input and output results.

The metric which may provide some indication is the absolute difference in the u’ v’ values. Further work is underway to establish whether or not other known metric, e.g. DeltaE2000, could be applied. However, DeltaE2000 was developed for SDR images and so does not, necessarily, extend to HDR images.

**Table 2: Source RGB values.**



**Table 3: HLG OETF -> HLG EOTF @ 4000 cd/m2.**

**Table 4: HLG OETF -> HLG EOTF @ 2000 cd/m2.**

**Table 5: HLG OETF -> HLG EOTF @ 1000 cd/m2.**

**Table 6: HLG OETF -> BT.1886 EOTF @ 100 cd/m2.**

**Table 7: BT.2020 OETF -> BT.1886 EOTF @ 100 cd/m2 (All within a BT.2020 Colour Space).**

**Table 8: BT.2020 with knee function OETF -> BT.1886 EOTF @ 100 cd/m2 (All within a BT.2020 Colour Space).**

**Table 9: BT.709 OETF-> BT.1886 @ 100 100 cd/m2 (All within a BT.709 Colour Space).**

**Table 10: BT.709 with knee function OETF-> BT.1886 @ 100 100 cd/m2 (All within a BT.709 Colour Space).**

# Discussion & Conclusions

This report has demonstrated that hue distortions are present when comparing the image achieved from an HDR images directly against the SDR compatible image. However, as shown with the results (and demonstrations), this task is inappropriate without the context of the legacy SDR image.

When the SDR legacy system images are compared to the SDR compatible images it can be shown that the level of distortion between the compatible image and that derived from SDR is comparable. Comparing the results (u’ v’ or final RGB ratios) from Table 7, the output from the SDR compatible SDR image against those in Table 8and Table 9, the SDR images created from legacy SDR systems, the magnitude of the errors are very similar. Consequently we conclude that the colour distortions reported by ARRIS primarily illustrate the limitations of SDR TV rather than a lack of compatibility of the HLG signal.

# Further Work

Although the distortion in the hue for the Orange highlighted in this report is noticeable, the BBC believes this distortion to be approximately a worst case scenario. Work is currently underway to establish the hue values which are worst affected. Initial work has focussed on the testing of the EBU 709 test colours, as shown in Figure 4.



Figure 4: Standard EBU 709 Test Colours (Illustrative only).

Some preliminary data is shown below.

Table 11: Standard EBU Test Colour Source Data.



Table 12: HLG OETF -> HLG EOTF @ 4000 cd/m2**.**

Table 13: HLG OETF -> BT.1886 EOTF @ 100 cd/m2 (All within a BT.2020 Colour Space).

Table 14: BT.2020 with knee function OETF -> BT.1886 EOTF @ 100 cd/m2 (All within a BT.2020 Colour Space).

The analysis for the full range of colours is on going, but will be reported as soon as the results are available.

# References

1. A. Luthra, D. Baylon, K. Minoo, Y. Yu, Z. Gu, “Some observations on visual quality of Hybrid Log-Gamma (HLG) TF processed video (CE7)”, ISO/IEC JTC1/SC29/WG11 m37543, February 2016, San Diego.
2. T. Borer and A. Cotton, “A display independent high dynamic range television system”, International Broadcasting Convention (IBC), Amsterdam NL, September 2015, http://www.bbc.co.uk/rd/publications/whitepaper309