Panasonic proposed Studio system SDR / HDR Hybrid Operation Ver. 1.3c

August, 2017

Overview

Improving image quality and impact is an underlying goal of all video production teams and equipment manufacturers. Over time we at Panasonic have taken approaches such as increasing resolution and advancing compression technology.
In recent years, the advancement of image display technology, has enabled presentation of images exceeding the capability of standard television including expansion of both expressible dynamic range and color gamut.

Changing the published standards for terrestrial broadcasting as public infrastructure is more than simply a technical issue, but for cable, satellite and over the top (OTT) internet video delivery, a UHD / HDR / BT.2020 based standard is planned, with the goal of expanding resolution, dynamic range, and color gamut.

For live broadcast images utilizing these new standards (UHD, HDR, BT.2020 color gamut) distribution must include a simultaneous “normal” HDTV signal for the current broadcasting pipe, and do so without a significant cost increase.
In this paper, we will explain technological developments for image production equipment so far as Panasonic seeks to realize an UHDTV future.

Live broadcast on HDR

The process for creating HDR video, for pre-recorded and post-produced content is very different from that of a live broadcasted event.
In the first case, post produced HDR image finishing (grading), utilizes specific tools, and an elaborate process to painstakingly fine tune the image on the evaluation monitor(s) and deliver the final results to the viewer so there are few chance of failures (i.e., poorly represented images).
In the case of live broadcast, the video quality is determined in the camera, with minimal downstream correction added by the switcher. Since the video quality is confirmed in near real time and it is shown to the viewer as it is; the camera must have a means of determining the video quality and avoiding a failure .

As mentioned above, with live broadcasting, we will produce new images in new standards (UHD, HDR, BT 2020 color gamut) for new video distribution systems, and simultaneously deliver existing video standards (HD, SDR, BT.709 color gamut) therefore the camera system must create images in both standards without difficulty.

> NB:
> In this paper we will describe UHD, HDR, BT.2020 color gamut in the aggregate as a new standard image, but we can handle resolution, dynamic range and color gamut separately as it seems that the HDR image in HD resolution with or without BT.2020 color gamut is viable for delivery in many applications.

HDR in live broadcast BT. 2084 or HLG?

The primary display characteristics under consideration for HDR are BT.2084 (PQ) standard based on the requirements of the reference display system, and HLG (Hybrid Log Gamma) focused on the requirements of the live production system - cameras, switching etc. HLG follows the example of the current BT.709 gamma in that it is a relative system that expresses black near zero and peak luminance at 100% of the signal. BT.2084 specifies the brightness on the screen of the display in absolute value, hence the name PQ which stands for *perceptually quantized*. PQ is an easy-to-understand system for the cinema or to show packaged media or streaming movies in the home as intended by the producer. PQ is an appropriate standard when creating images with grading and post-production where post viewing conditions are well standardized.

In a UHD Blu-ray Disc package intended for HDR distribution (primarily of movies) HDR10 is standardized as a characteristic. HDR10 is a subset of the full PQ curve, thus it appropriately matches the directors intent.
On the other hand, for live broadcasting, considering simultaneous output with the current standards (HD resolution, SDR, BT.709 color gamut), and TVs with various luminance performance capabilities, HLG material can to make use of the camera or display’s maximum

dynamic range and only contrast levels will vary. In addition, the HLG characteristic considers compatibility with the current HD SDR signal to be simulcast.

The HLG signal characteristic is specified as part of the ITU-R BT.2100. Standard alongside PQ.

	BT.709	BT.2020	BT.2100
Resolution	HD	4K, 8K	HD, 4K, 8K
Frame Frequency	24/1.001, 24, 25, 30/1.001, 30 50, 60/1.001, 60	24/1.001, 24, 25, 30/1.001, 30 50, 60/1.001, 60 120/1.001, 120	24/1.001, 24, 25, 30/1.001, 30 50, 60/1.001, 60 120/1.001, 120
Display Method	Interlace Progressive	Progressive	Progressive
Dynamic Range	SDR	SDR	HDR PQ (BT.2084) HLG
Color Space	BT.709	BT.2020	BT.2020
Bit Depth	8, 10 bit	10, 12 bit	10, 12 bit

Table - 1

Live camera output: HLG? or Log?

Even if HDR broadcasts are delivered under the HLG standard, there are cases where the same content may later be converted by another PQ based distribution path such as a Blu-ray package; the signal for Blu-ray HDR will be encoded with the PQ-based standard HDR 10. For this reason, it has been proposed that an interim Log characteristic should be used in live production. Although this would add additional conversion requirements at all viewing outputs the argument for this approach is that the log signal carries the full camera dynamic range and can be converted equivalently to HLG for the live output and to PQ for packaged media – e.g., HDR10 material converted from a Log signal would be superior to HDR10 material cross converted from HLG.

Practical differences converting HLG to PQ vs Log to PQ:

We start with an assumption that live broadcast content should be limited to a 1,000 nit display. Why such a limitation?
Currently, the luminance of the latest consumer TV set is set to 1000 nits as a certain upper limit, ITU etc., the industry assumes that the brightness of the TV set to be 1000 nits at the time of conversion of PQ and HLG so any dynamic range above 1000 nits will not be viewed on consumer TV at this time. It has also been suggested that high brightness is too dazzling for both the film producer and the viewer and eyes simply get tired. So brightness levels beyond 1000 nits will surely need to be carefully managed and even if viable for post produced content may never come into use in live production.
If the content is limited to 1000 nits or less, there is no loss between grading from HLG cross conversion and the ST.2084 content completed by grading from Log.

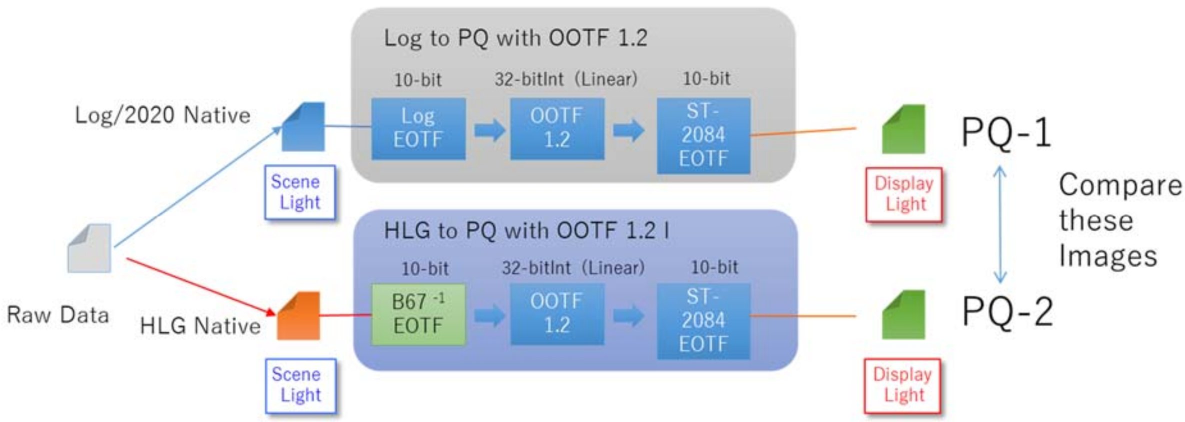


Figure – 1

Another possible source for fidelity loss is if the gradation resolution from an HLG cross conversion is less than Log source when both are only 10 bits. We don't believe this will incur an observable loss because the downstream signal exchange and distribution are performed on the basis of 422 10 bits maximum, and any errors will be beyond the limited gradation expression capability of the final viewers display.

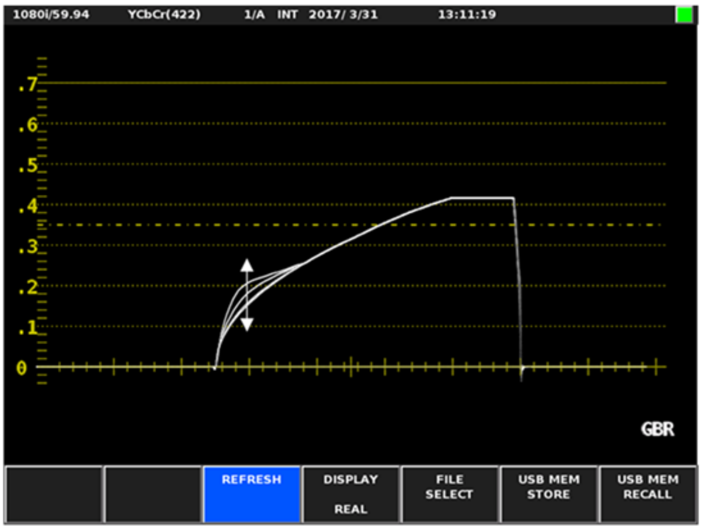
Furthermore, when the switcher system is configured on a Log basis, it is necessary to convert any HLG signal feed sent from other facilities to Log, and convert back again to HLG, so the necessity of equipment and conversion errors may grow.

While ongoing technological development may eliminate concerns in the future, at the present time a live production system based on HLG has the following advantages:

(1) Camera output can be used for delivery or monitoring as it is, so no need for conversion equipment from Log to HLG for QC display or playback display in the case of a recorded image
(2) Camera output can be sent directly to any HLG compatible monitor
(3) Commercially available TV without log conversion functions can be used for video confirmation
(4) There may be differences among Log capable displays due to differences in the maximum brightness level but the entire signal is guaranteed by the HLG monitor.
   Potential for errors introduced by misconfigured conversion equipment is eliminated by unifying a system to HLG.

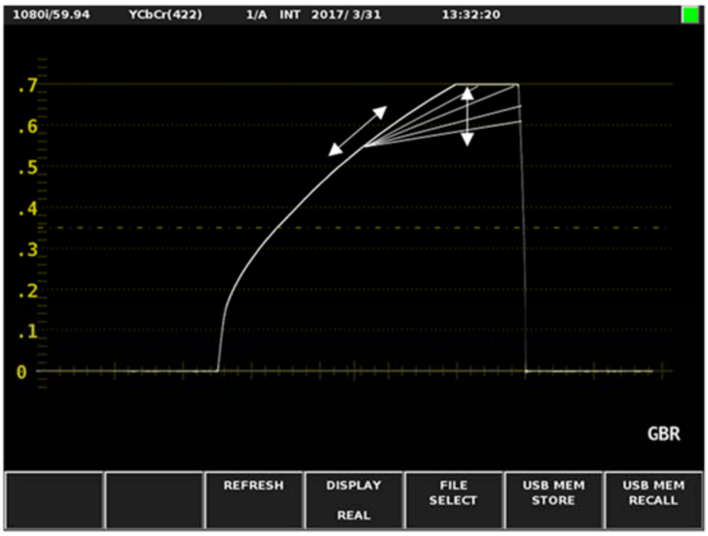
Live Output HLG signal Adjustment

SDR studio cameras are equipped with various image manipulation functions such as black gamma, knee adjustment, color matrix adjustment, and so on to manage difficult scene content and provide more tools to deliver a desired look.
In HDR shooting, the same image manipulation functions are expected.
Our HDR compatible studio cameras have introduced black gamma, knee adjustment, color matrix and similar image quality adjustment functions popular in SDR to the HDR image, and therefore can create an appropriate picture according to the scene content and the sensibilities of the producer. With these adjustment capabilities confirmation of this picture quality is critical, so we think that it is important to output directly viewable HDR from the camera with HLG so it can be viewed as it adjusted.



Adjustment of Master Black Gamma (HDR)

Figure – 2



Adjustment of Knee Point and Slope (HDR)

Figure – 3

Studio camera SDR / HDR Hybrid (Simultaneous output) operation

In the case of broadcasting and distribution of live events, terrestrial broadcasting in HD-SDR, with premium distribution in HDR (HD or UHD) performed simultaneously is expected to be the case early on. For SDR / HDR simultaneous broadcasting, it is unrealistic (not to mention prohibitively costly) to install separate SDR and HDR cameras and signal processing systems so SDR and HDR signals

from one camera output at the same time is a requirement.
Although there is only one iris adjustment for the camera, the operator (cameraman, or VE: video engineer) must adjusts the iris so that both the SDR and HDR have a pleasing image (based on the experience and judgment of the VE).The VE must confirm the images for both HDR and SDR, such that the HDR high brightness characteristics being touted for their viewer impact are appearing in frame (above 100% or the SDR range) while being able to express that image properly in SDR with all content 100% or less. It is necessary to confirm this has been achieved.

A camera capable of performing the SDR / HDR hybrid operation must provide functionality capable of achieving the above described iris adjustment without hesitation by the operator. For this purpose, it is necessary to develop functionality to define and manipulate the relationship **between** the HDR signal and the SDR signal output from the camera. Since the characteristic curves of SDR and HDR (HLG) are strictly defined, one might assume that it is only necessary to issue signals along the proscribed curves curve, but with a great deal of scene compositions if you do this the HDR compatible monitor will appear darker than the SDR compatible monitor. In addition, although the signal standard in SDR-TV assumes 100% maximum brightness 100 nits, in practice modern current displays tend to be adjusted to the full brightness capability, so the SDR monitor will be even brighter than the HDR compatible monitor, causing a kind of Inversion phenomenon. Hereinafter, to be described in detail using *Figure 4*.

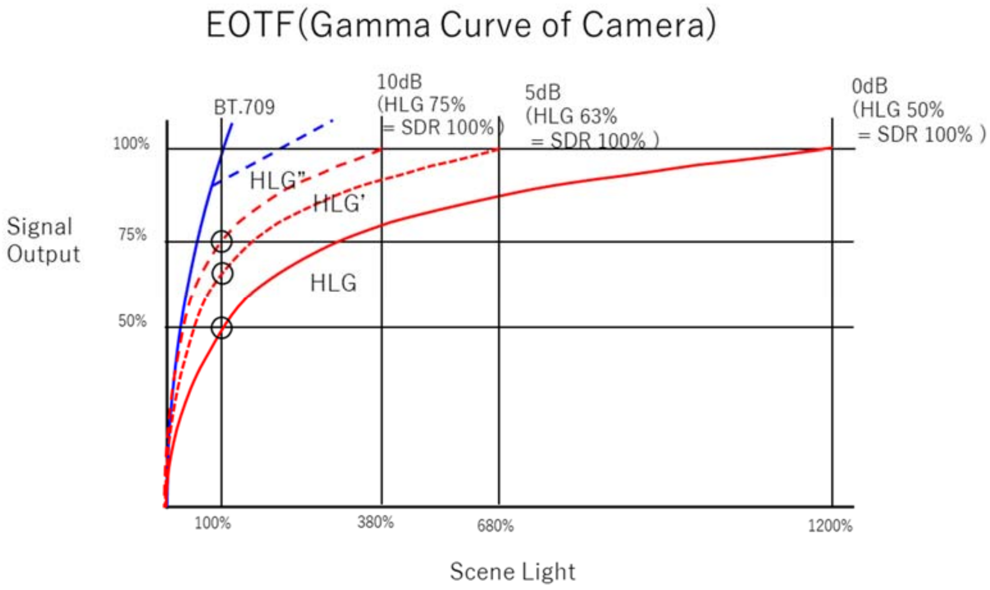


Figure – 4

Figure 4 shows the standard gamma characteristics of SDR (BT.709) in blue, and HDR (HLG / STD - B 67) in solid red.
Although 100% of SDR peak scene brightness is 50% of HDR-HLG, it is necessary to be aware that this graph shows the camera side conversion curve - optical electrical transfer function (OETF). The relationship between the HLG signal and the final brightness of brightness of the monitor display is the electro-optical transfer function (EOTF) and the combined relationship between the scene light (the brightness of the subject to be shot) and the brightness shown on the display is the optical-optical (OOTF) and this is shown in *figure - 5* below.

OOTF (Scene Light and Display Brightness)

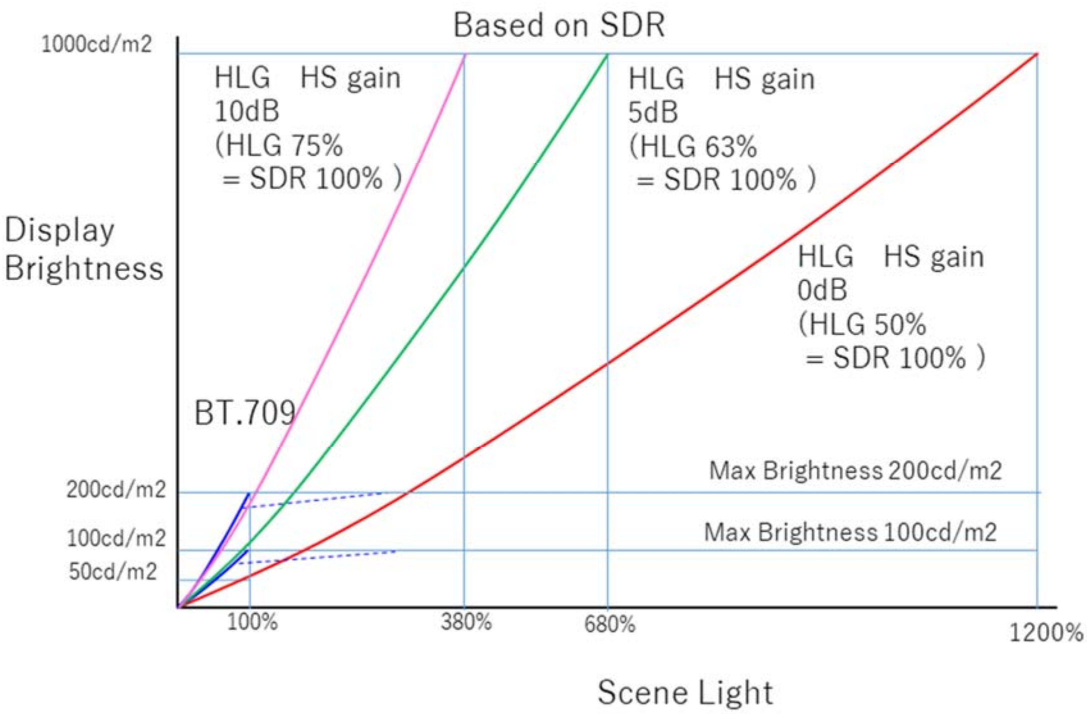


Figure - 5

When a white object is exposed with a level of 100% of the scene light, a properly adjusted SDR-TV follows the standard when displaying this as 100 nits, and HDR-TV can also show an object outside of the SDR TV range up to 1200% (12x) of the maximum 100% brightness as 1000 nits; but when exposing in this way the original SDR 100% white object will only display as 50 nits (*Figure – 5*)

Level of white object SDR-TV	100 nits on screen
Level of white object HDR - TV	50 nits on screen (half brightness of SDR - TV)

Thus at the normal brightness levels (presumably most of the content), the SDR-TV will be brighter (blue line).

Furthermore, in the current consumer SDR-TV, since the highest brightness of the screen tends to be set above 100nits, the SDR-TV looks even brighter, which means that for many scenes HDR will simply not match.

In order to match the HDR and SDR images for content within the SDR range, a gain difference can be applied to the HDR and SDR signals such that they converge in the lower exposures. Once this HDR/SDR difference or offset has been set to specific scene conditions it then becomes possible to set iris levels for both HDR and SDR by simply setting the iris to the proper SDR level relying on years of experience, and best practices.

With this technique it is also possible to match the image of the conventional SDR image for darker areas while still using the high dynamic range of HDR effectively in the HLG image.

Although it is necessary to set the optimum value for the gain difference between the HDR video and the SDR video by observation, it is assumed that it will be a fixed value for a given condition.

A study of the mapping method of SDR signal to HDR signal for SDR / HDR simultaneous output operation has revealed an effective offset level corresponding to 100% SDR signal to 75% HLG signal (equivalent to 200 cd / m 2 at peak 1000 cd/m2 : Pink line) and another mode (green line) corresponding to a 100% SDR signal corresponding to a 63% HLG signal (corresponding to 100 cd/m2 at a peak of 1,000 cd/m2) has been studied.

Difference between OOTF in HLG and OOTF in SDR

In the video system, a real scene (linear signal) is converted into an electric signal by a camera, and the electric signal is then converted into light (linear signal) of a display by a monitor. The conversion on the camera side is called the Opto-Electronic Transfer Function (OETF), and the conversion on the monitor side is called Electro-Optical Transfer Function (EOTF). Normally, the characteristic on the camera side is an inverse-geometric or inverse logarithmic, in other words that the dark areas are lifted and the bright areas compressed; on the monitor side the characteristic is geometric or logarithmic hence the reverse happens where highlight are lifted and dark areas compressed.

In the conventional SDR system (BT.709), the OETF on the camera side is a power function and the (less than unity) coefficient (gamma value) is typically around 0.45 (1 / 2.2), the EOTF on the monitor side is a power function with a 2.4 coefficient. This mimics the physical characteristic of the original cathode ray tube (CRT) displays, and it is not strictly a reverse characteristic to the camera so a slight ~1.2 power law remains, this is called OOTF (Opto-Optical Transfer Function) and is the characteristic of the whole system. Thus, OOTF is a conversion function between real scene and display light, and is not necessarily a linear relationship. The OOTF represents end to end image conversion between a real scene and a monitor display, and includes an adjustment that is an aesthetic choice of the producer.

Within the conventional SDR context, OOTF adjustment can be applied individually to red green and blue signals as R, G, B gamma, but in the HLG specifications in BT.2020, “gamma” is applied only to luminance. This is to avoid color distortion when applying a gamma adjustment. The gamma values of the OOTF are also changed according to the peak luminance of the display. This is to reproduce the same perceptual appearance regardless of the specific display’s peak luminance.

The differences in OOTF between HLG and SDR, include managing the increased dynamic range of HLG as has been discussed but also some small appearance differences (HLG appears to be thinner in color etc.) Managing the contrast differences has been addressed above but as color saturation and other differences have been introduced considering the design of the consumer TV set with receiving an HLG signal, we believe that it is preferable to stay within compliance with these regulations without attempting corrections.

Specific Control of gain (offset) and Knee to establish SDR / HDR image adjustment

In this paper we have explained the advisability of providing a gain difference or offset between HDR & SDR according to the scene for

the simulcast of SDR and HDR.
For a case where the screen is bright and there are many high luminance areas/objects (bright objects with a wide dynamic range), adjusting the gain difference by about -10 dB between SDR and HDR thereby setting the 75% point of HDR to the 100% level in SDR , matching SDR and HDR images become manageable.
With a narrow dynamic range image, setting a reduced gain difference offset becomes appropriate.
Thus setting the proper gain difference between SDR and HDR according to the scene brings out both characteristics and it becomes a practical solution to make HDR video by setting proper SDR video exposure.
It is not however recommended to dynamically change this offset gain during shooting. It is sensible to follow set the offset according to the larger contrast conditions which will likely not change for a given camera position. A consensus is building among HDR production teams accumulating experience of simultaneous shooting of HDR & SDR.

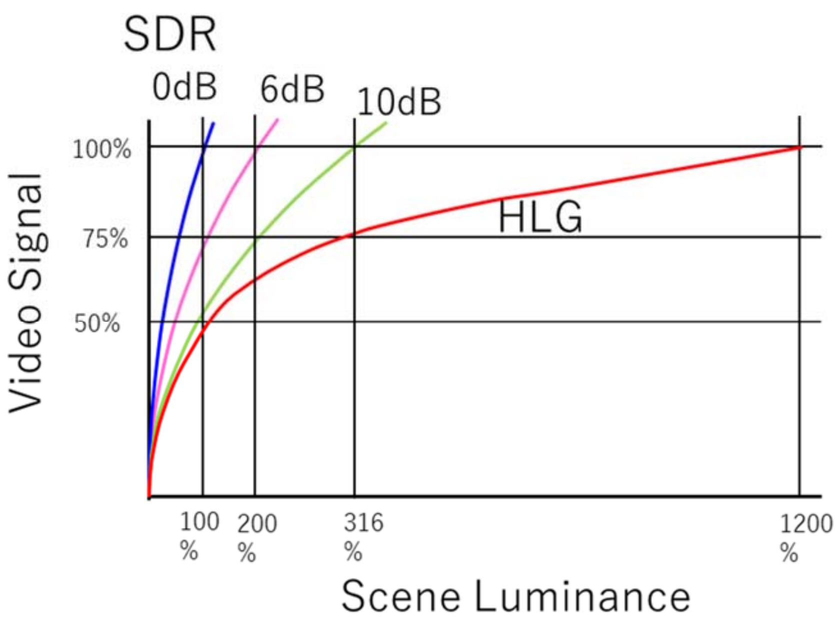


Figure - 6

HDR Knee control

In SDR image capture it has been possible to compress more dynamic range into the legal SDR signal contrast by utilizing the knee circuit. The knee takes much of the out-of-range bright areas the camera imager captures and compresses them into the top ~80%-100% of the SDR characteristic; engineers will adjust the knee point and slope to control these highlight areas. When the offset between HDR and SDR is reduced to match pictures there is now some unused dynamic range in the highlights of the HLG image that can be utilized for an HDR knee adjustment.

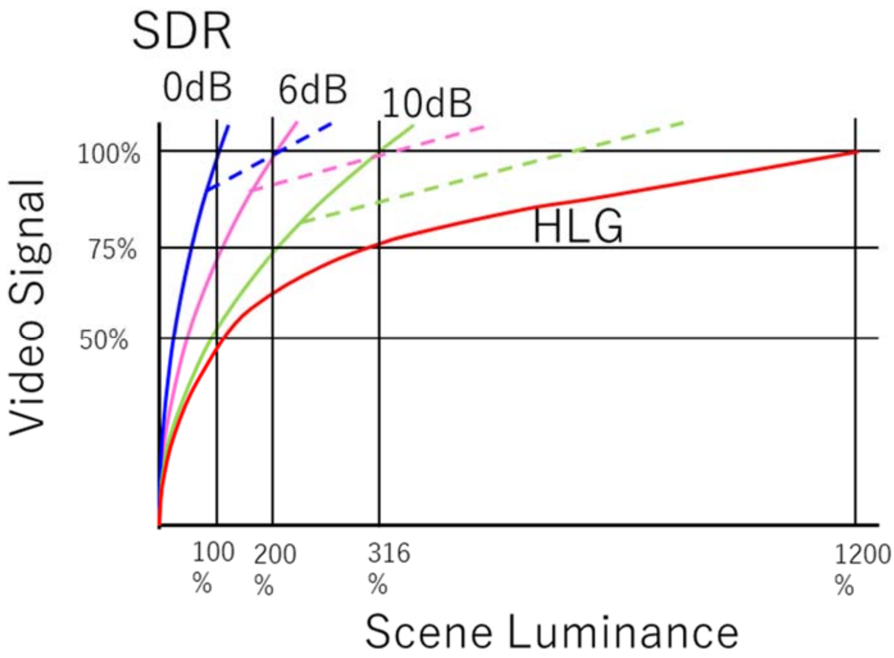


Figure - 7

Color gamut conversion BT.2020 and BT.709 color gamut

The UHD (3840 x 2160) signal standardized by BT.2020 has a dynamic range of HDR and also has recommended color gamut (also called BT.2020 color gamut) that is wider than the conventional BT.709.

In recent years, the expansion of the color gamut in display devices such as TVset has progressed along with brightness and contrast, and it seems that the future BT. 2020 color gamut will be used in a wider range of products. Even in the studio system, with the performance of the camera output, vision mixer and switcher, it is an expectation that BT. 2020 color gamut will be covered. Therefore it is necessary to be able to select the color gamut of BT.709 or BT.2020.

When the color gamut of the monitor is BT.2020, vivid colors exceeding the conventional BT.709 color gamut can be correctly transmitted and displayed. Care must be taken as accurate color reproduction cannot be obtained unless the color gamut of the camera matches the monitor or display.

VE operation During Simultaneous SDR / HDR Broadcasting - Summary

1. When assuming simultaneous operation of HDR and SDR, it is necessary to consider image output and exposure level suitable for both formats
2. To achieve matching exposure levels a predetermined gain difference/offset can be pre-set between the HDR and SDR signals (based on scene contrast levels) and then the video engineer or shader can adjust the iris level based only on the SDR video. In this way images are created that effectively utilize the high dynamic range of HDR while attaining correct SDR video as before and operation is transparent to the shader utilizing existing qc monitors and wave form monitors
3. The gain difference between the HDR video and the SDR video is realized in the downconverter section of the studio camera's CCU. In addition, conversion of characteristic curve, color gamut and knee processing are also performed here.
4. The same offset value is set for the newly developed HDR-SDR "downconverter" installed at the switcher output as the offset setting for the "downconverter" in the CCU. This makes it possible to have the HD output from the camera match the main line HD output from the final down converter, so accurate adjustments can be made at the camera side..

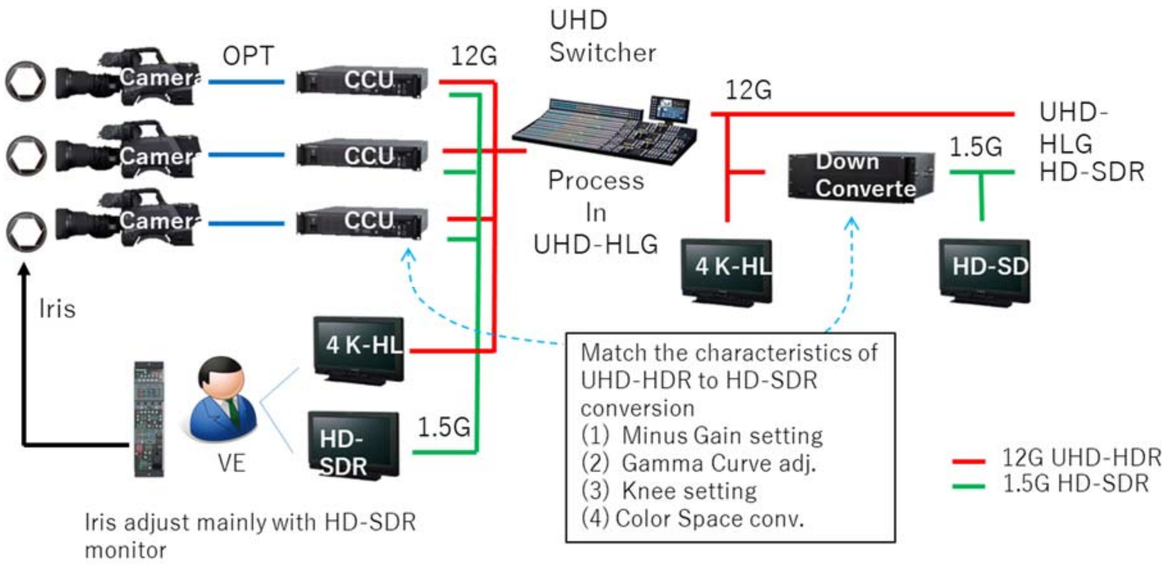


Figure 8

Switching in SDR / HDR Hybrid operation

So far, we have described SDR and HDR signals from studio cameras, and the necessary functions for the camera system to have sufficient manipulation of the images. Although using such methods one may established each parallel SDR and HDR signal and even set each to match the look of all other sources for the full set of HDR and of SDR sources, when considering simultaneous broadcasting, there is a switcher to consider. The switcher not only switches the matched video signals from the cameras but also performs video effects and graphics insertion. Effects and graphics must also be rendered for both the HDR and SDR product. Assuming cameras are matched then, how should producers and directors perform hybrid operation of SDR/HDR broadcasts including switching, graphics, and effects.
Here are two possible system configurations possible at this time:

Parallel operation of UHD-HDR and HD-SDR

Here a ganged switcher processes a UHD and HD signals completely in parallel, including effects, graphics and transitions. With current processing power it is conceivable to manage two signals (even when one is UHD) with optimal signal processing. Although this configuration has advantages such as the sense of a schematically redundant system and the ability to construct a system with the shortest possible latency, such a dual signal system with either two synchronized switching/processing platforms or massive bandwidth and processing power will certainly come with a high price tag, and the hardware investment would not be returned on traditional broadcast projects which might still represent a majority of rentals.

Core Operation in UHD-HDR

In this method, all processing is performed in the UHD-HDR BT.2020 space, and finally, since all HD, SDR BT.709 image data is a subset UHD-HDR, conversion to HD-SDR is performed at the output. In this case, only one signal processing engine for the switcher is sufficient, but the parameters at the time of SDR conversion will need to match the original intent of the production team utilizing the SDR camera outputs and SDR adjustments. From the viewpoint of quality image creation, it ought to be sufficient to apply the knowledge of HDR/SDR gain-offset setting (applied at the camera based on the contrast conditions) and the SDR knee settings. These settings are not adjusted dynamically so incorporating them into the SDR conversion can be managed. How closely the final SDR output image can be matched to the SDR QC image will be a addressed through ongoing experience and tools still in development

In both the parallel HDR/SDR and HDR to SDR output conversion methods, it will be necessary to prepare all the input images for HDR as required for UHD-HDR processing. For example reuse of stock content and images from the other video feeds/sources are most likely to be SDR, as will some graphics packages, these will need to be converted to HDR. The internal processing of an HDR switcher, will need all of its sources to be HDR in order to perform special effects and other processing, then output the HDR main line signal. It is practical for a switcher to operate in an all HDR mode to avoid an undue processing load on a switcher that may be reset for SDR on its next job. Thus there is a system requirement to convert SDR sources to HDR and apply also apply SDR broadcast characteristic to the

Output. It will also be necessary in many cases to convert BT.709 color space inputs to BT.2020 and of course upscale some HD to UHD, and do the reverse on the output. In order to simplify system architecture, simplify system upgrades and enable more flexibility in switcher choice we plan to provide a rack mount type signal conversion device that provides various conversion functions for multiple channels as a peripheral device to the switcher. Such a device can communicate with cameras (to enable better matching of camera SDR and final broadcast SDR look) and as a separate device will be ready for operational upgrades or to be excluded from the design in the event of a pure UHD system.

Conclusion

In this paper, we have discussed problems and solutions as they stand in the summer of 2017 to enable simultaneous distribution of SDR and HDR. This simultaneous distribution is a global concern for broadcasters and rights holders aiming for advanced operation, and research experimentation and discussions are ongoing. To realize a system that achieves both a high performance and practical operation, consideration will be made to further the discussed approach, but as new data is collected develop a different approach from this paper may be attempted as well.

As Panasonic, it is not our position to dictate best practices this early in the life of HDR. We would prefer to respond flexibly to building better systems by repeated discussions with the users, and further testing.