What's "SR Live for HDR"

Workflow proposals for 4K HDR and HD SDR simultaneous Live Production

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Abstract

The use of High Dynamic Range (HDR) technologies for live production applications represents a new and exciting technical challenge, comparable to other fundamental innovations in the history of content creation for live television. A key challenge has been the addition of 4K HDR production techniques to the existing HD live production environment while simultaneously maintaining the skill sets and workflows demanded to support the creation of content for the current HD marketplace. Production issues, such as, the requirement for additional crew operators and new equipment to support the 4K HDR production, have rapidly become financially prohibited. Even if we could overcome the financial constraints other technical problems still remain: unlike the development of Standard Dynamic Range (SDR) production techniques, today we have no operational practices nor shooting recommendations, such as adjustments of white reference levels, highlight and shadow range extensions, etc, for HDR live production applications.

In order to find solutions to the aforementioned issues, Sony has carried out extensive technical research and conducted numerous HDR trials with broadcast and production communities. In this White Paper on "What is SR Live", Sony would like to share the knowledge and experience gained during the development and trials of technologies and workflows for HDR Live Production.

Production Workflows for the Simultaneous Creation of 4K HDR and HD SDR Programs

In the current transition from HD to UHD (Ultra-HD, 4K and 8K) television many production companies have decided to future-proof their investments in video acquisition equipment by purchasing 4K cameras for Studio and Outside Broadcasting operations.   In 2015 Sony introduced the first 2/3-inch camera in the industry with RGB CMOS sensors with true 4K resolution and capable of up to 8x High Frame Rate (HFR) in HD and 2x HFR in 4K : the HDC-4300.   This camera chain has rapidly become a de-facto acquisition system for HD/4K studio and sports applications all over the world.

One special characteristic of this 4K camera is the design of its Baseband Processing Unit (BPU) which employs multiple digital signal processing engines. As such, the BPU, once paired with the HDC-4300 camera head, can output simultaneously 4K and HD signals.   It also enables the assignment of different OETF (Opto-Electrical Transfer Function) curves onto the various formatted outputs independently, so that 4K HDR and HD SDR simultaneous productions can be carried out from one single camera chain.

One of the most important advantages of performing simultaneous productions from a single camera chain is that the tone and/or look of the pictures can be maintained between the various output signals.   On the other hand, there are many scenes where the operator wants to adjust optimally the brightness levels for each of the HDR and SDR output signals.   For example, if the aperture of the iris of the camera is adjusted to make the white reference level of the SDR signal equal to 100%, then the HDR picture will look unsatisfactory, exhibiting a dim overall brightness and lack of contrast.   Alternatively, if the diffuse white level of the HDR signal is set to around 300%, then the HDR signal will look "punchy" and with great contrast, but at the expense of the SDR image being washed out and with its highlight elements clipped.

Making use of the multiple processing engines in the BPU, Sony has invented and introduced a "SDR Gain" adjustment feature in the camera system.   This feature allows the setting of the optimal gain difference between the HDR and SDR signal paths, allocating perfectly the brightness range necessary for each of the 4K and HD signals (see figure 1).
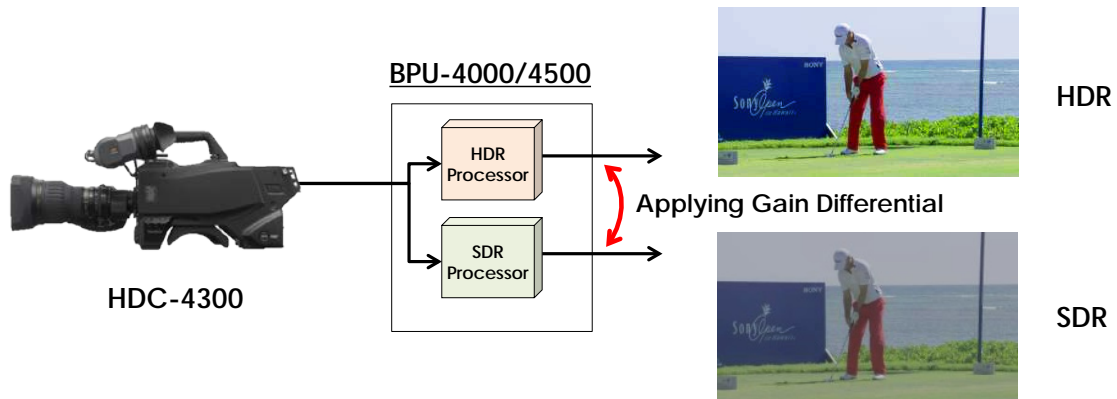
4K-HDR & SDR Simultaneous Production

Figure1: "SDR Gain" process in the BPU

In general terms, rather large gain difference values should be applied during the shooting of scenes under high brightness conditions, while lower values are best selected for dim shooting conditions.   The actual value must be determined on a case-by-case basis, with most commonly values selected in the range of -6dB to -10dB of differential gain.

The other important points for consideration, while setting the SDR Gain in multiple camera production environments, are the following:

- To set the same value of SDR Gain across all cameras
- Do not change the value of SDR Gain during actual shooting (of course, real-time camera shading is perfectly maintained as in conventional SDR live production).

Execution of Camera Shading and/or Painting on the HD SDR domain

The SDR output from the BPU is returned to the camera viewfinder (VF) so that the camera operator can perform framing and/or focusing based on images similar to the ones they use in today's HD live production.   One of the key benefits of utilizing the feature of "SDR Gain" is that the video engineer (VE) or camera shader can perform real-time camera shading/painting operations based on ordinary SDR signals, as long as the appropriate gain difference between the SDR and HDR signal paths is set prior to shooting.   This technique allows the VEs to

define the look of the production images based on their experience and well-honed skills gained from HD productions with HD waveform monitors, SDR display devices and system infrastructure.

As the SDR images are optimized within their limited dynamic range and color space (BT.709), the corresponding HDR images are also optimized within the higher dynamic range provided by the 4K camera and with the wider color gamut of BT.2020.

In summary, the operational techniques for simultaneous SDR and HDR live production are:

- Set up appropriate values of "SDR Gain" prior to shooting.
- Maintain constant the value of the SDR Gain across the multiple cameras and while shooting

Simultaneous production for both 4K HDR and HD SDR by S-Log3 as intermediate production format

Please see figure 2 below for an actual production system based on the proposed workflow.

HDR & SDR Simultaneous Production (Parallel System)
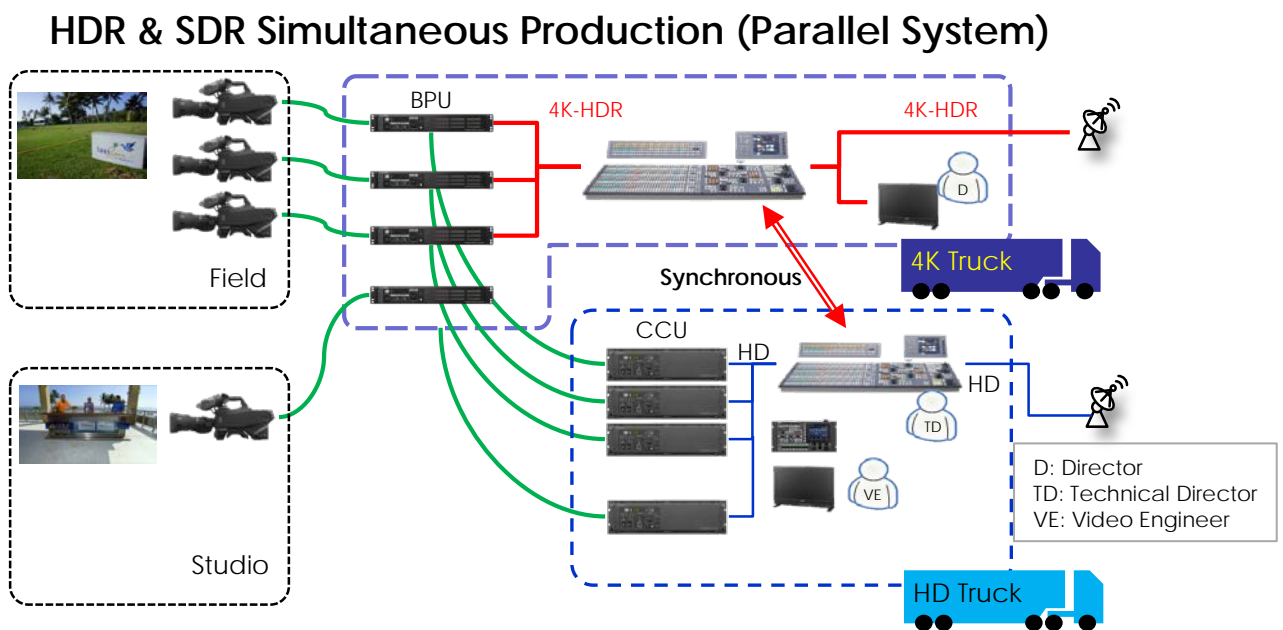

Figure 2

Since there are two formatted outputs, 4K HDR and HD SDR, from the BPUs, it is possible to operate on the HDR and SDR signals by means of independent production systems.   However, this approach would not only be redundant but also financially impractical.   Instead, we would like to propose to use the HD SDR outputs from the BPUs only for operational adjustments, while maintaining the 4K HDR signal as the master production format which, at the end of the processing chain, can be converted to whatever HDR or SDR formats required for final distribution. This new approach makes the overall system much simpler in terms of workflows and very cost-effective.

We also propose to unify the processing of the HDR signal in the production environment by the use of the S-Log3 process, since it is the most suitable OETF curve for the creation of an intermediate production format (see figure 3).

At the end of the live production workflow there exist requirements for a high precision conversion process.   This is necessary for the generation of either HLG (Hybrid Log Gamma) or PQ (Perceptual Quantization) distribution masters from the S-Log3 production format, with high levels of picture quality.
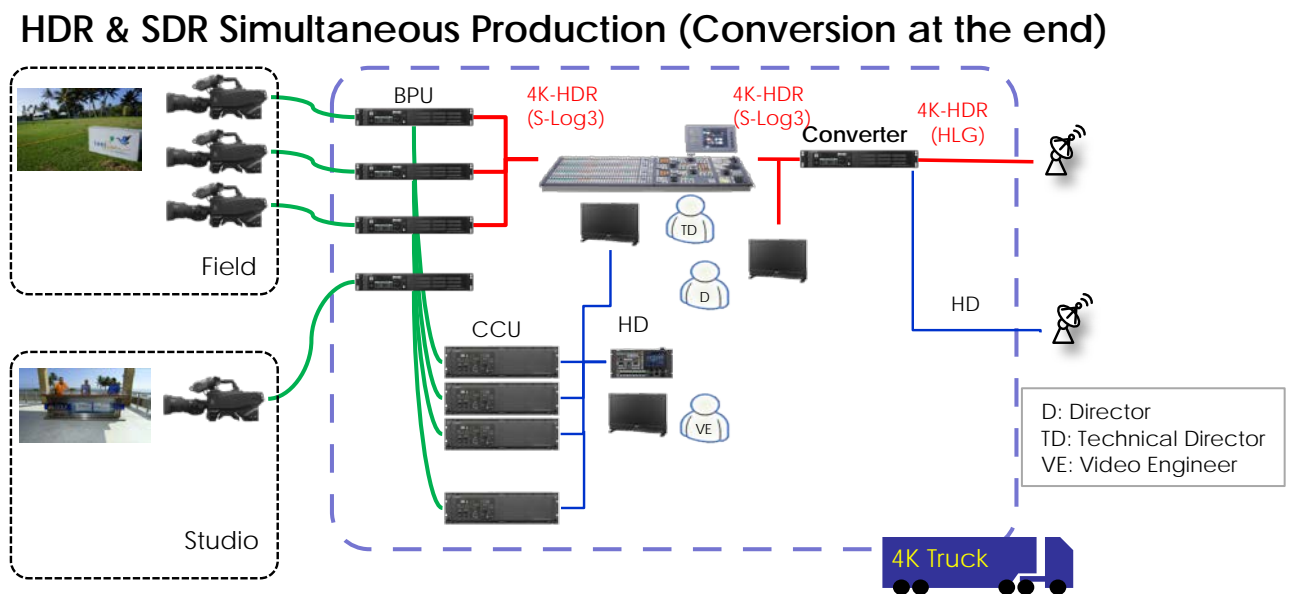
HDR & SDR Simultaneous Production (Conversion at the end)

Figure 3

Look oriented OOTF

Sony is planning to introduce early in 2017 the HDRC-4000 – a HDR converter for production applications.   This converter supports "AIR Matching" (Artistic Intent Rendering) – a conversion feature which performs real-time conversion of HDR formats on an "as seen" (Scene Referred) basis.   Before describing the "AIR Matching" process in more detail, let's clarify how the "look" of a televised signal is defined.

The digital signal processing and conversion of the scene light captured by the camera are carried out in "linear space" with high numerical precision.   However, the output signal of the camera goes through a non-linear gamma curve – with gain lifts of the shadows and mid-tones of the image and compression of its highlights.   These signals are then converted back to linear light at the display/monitor side by applying a corresponding inverse of the gamma curve. These non-linear curves are known as "Camera Gamma" (0.45) and "Display Gamma" (2.4) curves.   These gamma characteristics were originally introduced to enable the transmission of analog television signals over the limited S/N values of transmission channels and to accommodate the input/output characteristics of CRT displays (Cathode Ray Tube).   When the display devices (consumer and professional) changed from CRTs to fixed-pixel, flat panels, such as LCD, it was necessary to redefine the non-linear gamma characteristics of the display device. The ITU-R-BT.1886 standard now defines a Display Gamma value of 2.4.   However, the Camera Gamma has remained unchanged, with the value of 0.45 (1/2.2), as defined in ITU-R-BT.709.   As a consequence, the end-to-end (from Camera to Display) transfer characteristic is no longer linear (unity in value) but slightly non-linear (a value of 1.1) – with a slight departure from linearity in the shadows and mid-tones of the picture.   Such performance characteristic over the total system – from incoming light to the camera to reproduced light on the display – is called OOTF (Opto-Optical Transfer Function) or "System Gamma".

As mentioned above, the shape of the present HD OOTF shows a slight attenuation of the dark areas of the picture and slight enhancement of the bright areas resulting in images with crispiness and contrast within the parameter range defined by HD SDR imaging (BT.709).

In July 2016, a new international standard for HDR imaging was standardized for Full HD progressive (1080 50/60P) and UHD signals (Ultra HD, commonly known as 4K and 8K).   This international standard is the ITU-R-BT.2100 and describes two different

approaches to establish HDR in the production of UHD signals.   Please see figure 4 below.
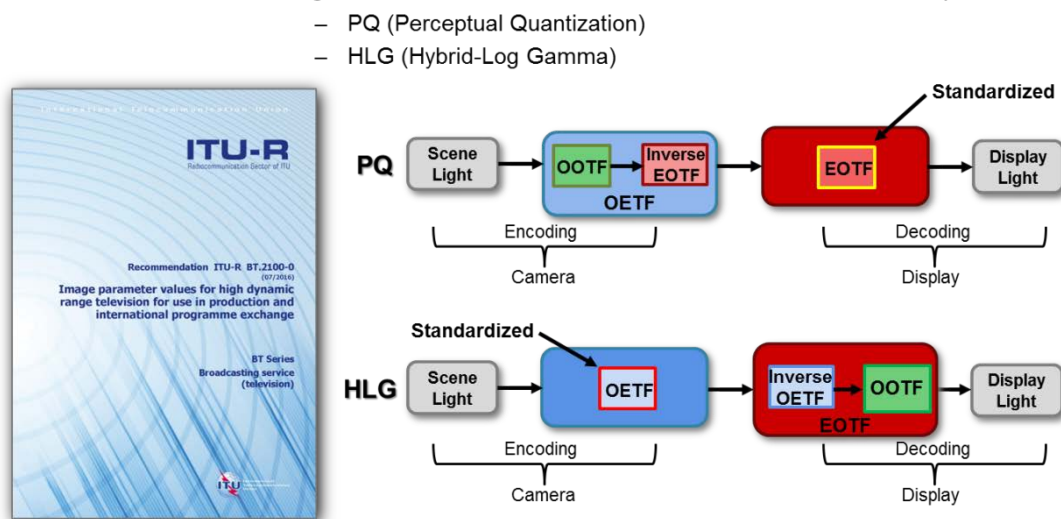

Figure 4: Recommendation ITU-R BT.2100-0 (2016 July)

In one definition, with the use of PQ (Perceptual Quantization), the BT.2100 standard establishes a precise EOTF (Electro-Optical Transfer Function) to be applied in the display device, while the OOTF is applied at the origination side. This approach is known as a "Display Referred" approach since the conversion to light from the digital information is defined in "Absolute" terms: every digital code value represents a prescribed brightness level of light on the display.

In the other approach defined in BT.2100, the Hybrid Log Gamma (HLG), an OETF is precisely defined for the creation of images, while the OOTF is implemented in the display.   The HLG approach is known as a "Relative" system, as it is also the case for today's television system (HD SDR).   The HLG approach describes the relative appearance of light from capture to display and minimizes the difference in looks at the receiving display based on its brightness capabilities.   The OOTF of the HLG system is variable depending on the peak luminance of the display device and does not require the use of transmitted additional information (metadata) from the origination side.

When considering the creation or direct cross-conversion between these two HDR formats it is important to pay special attention to the differences of the overall OOTF (System Gamma) between these approaches.   Instead of facing such complex processes during the stages of conversion, Sony has concluded that the best

approach is to utilize the "AIR Matching" feature of the HDRC-4000 device, especially in live applications.

Characteristics of S-Log3 as Intermediate Production Format

The original S-Log signal was invented by Sony in 2000 for its application in the first Sony digital cinematographic cameras.   This log curve was carefully designed to match the dynamic range and tone characteristics of the sensors in the early Sony HDR cameras.   The S-Log curve has evolved to an S-Log3 curve with a maximum capability to capture up to 4000% of light exposure.

Presently, state-of-the-art cameras exhibit in the order of 1300% of exposure performance, or in other words around 14-15 stops of dynamic range capability. S-Log3 optimally maps this wide dynamic range onto the 10 bits description of today's television professional digital interfaces (a 12 bit implementation is also possible for future digital interfaces).   It is said that the S-Log3 is very efficient in preserving all the image information from very dark regions to extreme highlights. The S-Log3 process also enables optimum signal manipulation by color graders and colorists in real-time, for a wide range of source material during the post-production process.   The question has then been raised if S-Log3 could be a most suitable format for the creation of HDR in live applications.   The answer is given in the paragraphs below.

Sony has recently defined S-Log3 OOTF and incorporated it into selection of EOTF as S-Log3 (Live HDR) on the BVM-X300 V2, our 4K RGB OLED Mastering Monitor.   In order to expand the use of S-Log3 into live production operations, Sony will continue expanding the use of S-Log3 (Live HDR) to other devices in the series of Sony broadcast monitors.

The key concept of S-Log3 OOTF is to create the best "contrast", and "punchy" HDR images while maintaining a high degree of compatibility with the characteristics (looks) of the present SDR OOTF.   Referring to figure 5 below, within the range of SDR exposure (100%), the S-Log3 curve closely follows the tone rendering behavior of the BT.709 OETF, while the PQ and HLG curves exhibit a dimmer rendition.   When the SDR compatible region of the S-Log3 signal is used as a production intermediate format, it ultimately enables production people to extend their grading/shading skill sets of the SDR imaging world to the creation of the very best HDR images.

OOTF Comparison (～100%)

Display Luminance (nit)
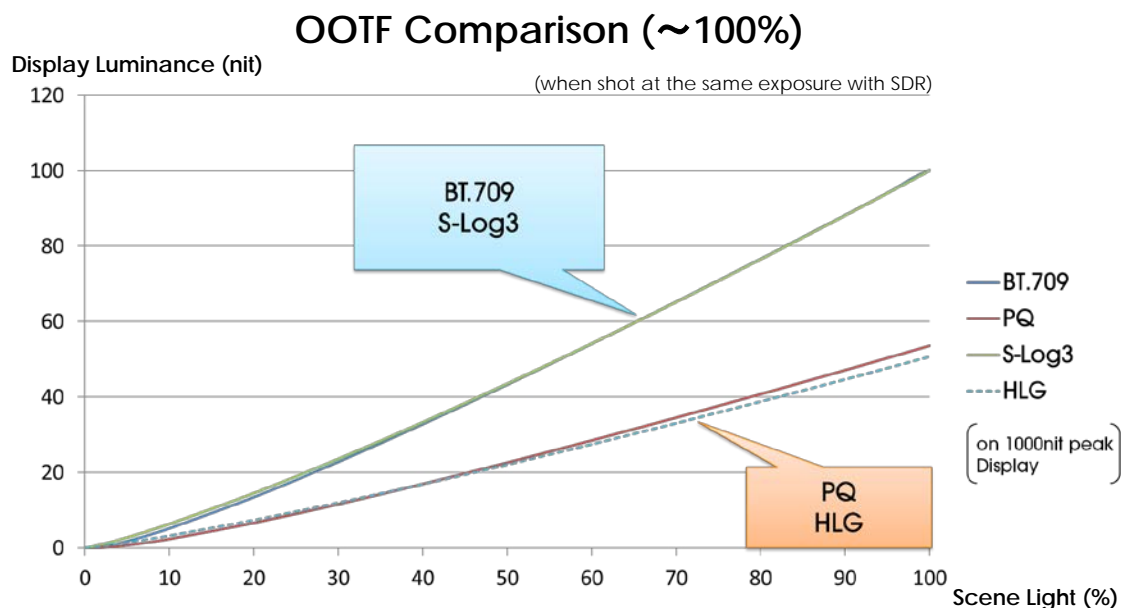
(when shot at the same exposure with SDR)

Figure 5

At the end of the production process, the S-Log3-based production format or intermediate finished materials can be easily converted into any desired distribution format: either to HLG, PQ or SDR, on an "as-seen" basis by the HDRC-4000, HDR Production Converter.　Such conversion feature is called "AIR Matching" in the HDRC-4000.

Another unique characteristic of S-Log3 is that it minimizes losses in direct cross-conversion between PQ and HLG by serving as an intermediate step in the conversion and preserving their respective dynamic range and tonal characteristics.

The technical specification of S-Log3 has already being published and it is open to the public.　It is gratifying to Sony that other camera manufacturers and industry players are adopting the use of S-Log3 in their products and/or services. Detailed information about S-log3 can be obtained at, http://www.pro.sony.eu/s-log3

Utilization of HDRC-4000

The HDRC-4000 not only supports HDR to HDR conversion – S-Log3 to HLG or PQ, but also HDR to SDR and even 4K HDR to HD SDR down-conversion is available. It is important to remember to use the value of "SDR Gain", which was set upstream for simultaneous SDR/HDR signal creation, in order to properly reproduce the down-converted HD SDR signal.   This is one of the main reasons why a fixed value of "SDR Gain" is recommended for the highest quality of HD SDR.

When considering an actual production environment, a variety of source materials, formats and devices from multiple vendors are expected to be found, and which must be converted into 4K S-Log3 to accomplish the final production master. Referring to figure 6 below, it is highly advantageous to utilize the HDRC-4000 for initial conversion into the S-Log3 processing space.

Figure 6: Precision Conversion to/from 4K S-Log3 HDR

In this white paper we have tried to minimize the discussions of other topics related to the production of HDR signals. In particular we have not discussed issues involving changes in color spaces, but it is expected that a mixture of BT.2020 and BT.709 signals will exist in any television production.   In order to unify all the operations during the live production into one single production intermediate format conversion of color spaces is necessary.   The HDRC-4000 converter fully supports cross-conversion of color spaces, I/P (Interlace to Progressive) and signal resolution in addition to HDR to HDR conversion.

Conclusion

As a final comment of the proposed workflow and techniques for the simultaneous creation of 4K HDR and HD SDR in Live Production applications, Sony has named this workflow "SR Live". "SR" stands primarily for "Scene Referred", which is one of the key properties of the S-Log3 process.

Sony is very glad in proposing this production technique to the industry at large, and we have the confidence that it enables the entire workflow from image capture though production and final distribution for the very best 4K HDR imaging and the most efficient way for the simultaneous creation of 4K HDR and HD SDR live television programs.