grass valley
A BELDEN BRAND

HDR A Guide to High Dynamic Range Operation for Live Broadcast Applications

Klaus Weber, Principal Camera Solutions & Technology, December 2018

WHITE PAPER

TABLE OF CONTENTS

The status of the different solutions for extended dynamic range operation including wide color gamut and HDR/SDR-compatible workflows and their operational aspects.

Introduction

HDR is winning over consumers today because of its ability to deliver a visibly wider range of highlights and shadows, as well as more realistic color and detail. Thanks to its contrast ratio, which is much closer to the conditions found in real life, HDR allows image reproduction that is much closer to reality. Furthermore, HDR also allows more dependable results under difficult shooting conditions — such as irregular lighting or partial shade — found at many outside broadcast productions. An additional advantage of HDR is that it is fully format-independent, and does not need any specialized viewing conditions to show its advantages.

For broadcasters and content creators, embracing an HDR workflow process raises a number of questions and poses some challenges. Most notable is the need for a parallel SDR/HDR production workflow, one where the signal can be adapted with up/downmapping as required to mix and match incoming content formats and output signals without sacrificing any quality. For example, operators may need to integrate existing SDR content into new HDR productions, or may need to send HDR content to SDR multiviewing screens in the studio. In either case, the producer's intent for each individual signal must be maintained.

This whitepaper explains the challenges and the best possible solutions to produce native 10-bit HDR in either HD or 4K UHD, and deliver that content in HDR and SDR simultaneously, as necessary, thanks to the high-quality conversion that can be done with a downmapping process. These solutions provide native support for both of today's worldwide standard: Hybrid Log-Gamma (HLG) and Perceptual Quantization (PQ or SMPTE ST 2084).

HDR Standards

ITU-R, the radiocommunication sector of the international telecommunication union, have published in 2017 their Recommendation ITU-R BT.2100: Image parameter values for high dynamic range television for use in production and international programme exchange.

There they specify the HDR-TV image parameters for use in production and international program exchange using the Perceptual Quantization (PQ) (as specified under SMPTE ST 2084) and Hybrid Log-Gamma (HLG) methods (See Figure 1).

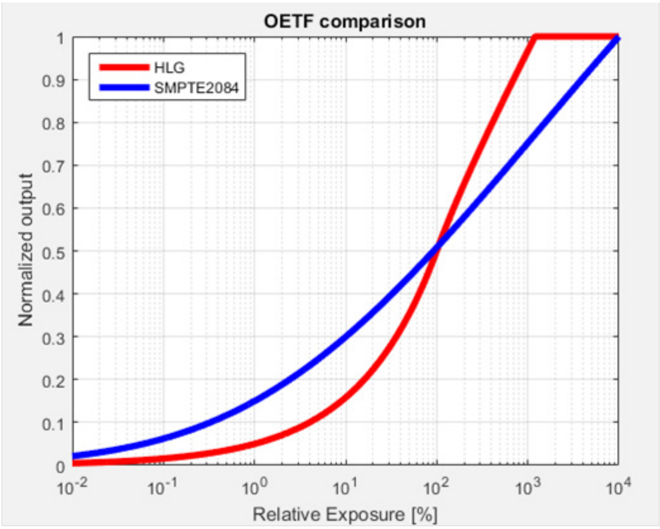

Figure 1 – OETF comparison HLG and SMPTE ST 2084 / PQ.

ITU-R BT.2100 recommends: *"…that for program production and international exchange of HDR-TV, the perceptual quantization (PQ) or Hybrid Log-Gamma (HLG) specifications should be used…high dynamic range television production and display should make consistent use of the transfer functions of one system or the other and not intermix them."*

This also means there are only these two standards specified for all live broadcast applications in production as well as program exchange. Any other production format that includes manufacturer specific logarithmic or RAW formats, which are often used in file-based workflows for digital cinematography applications, are not part of these ITU recommendations. The same is true for all consumer applications where the PQ standard as well as the HLG standard is widely adopted in all applications. This also means that any production not done in one of these two specified formats would need to be converted into one of them before they could be used for international program exchange or any form of distribution to homes.

Non-live file-based workflows allow use of 12-bit, 14-bit or even 16-bit signals, but any live production workflow available today is limited to 10-bit depth. This means in live productions conversion between different HDR production formats needs to be done in the 10-bit domain. Converting one 10-bit format into another 10-bit format will reduce the performance of the signal and should be avoided whenever possible.

Different fully native HDR workflows are available and will be described in the HDR/SDR Compatible Workflows section.

Wide Color Gamut

Recommendation ITU-R BT.2020: *Parameter values for ultra-high definition television systems for production and international programme exchange* specify for UHD applications a new color space also known as wide color gamut (WGC) which can reproduce colors that cannot be shown with the BT. 709 (HDTV) color space (see Figure 2.).

The BT.2020 color gamut allows reproducing close to 100 percent of all the natural colors (as defined by Pointer's gamut) where the BT.709 only allows to reproduce close to 70 percent of these colors. In combination with a larger range of brightness as provided by HDR operations, a much larger range of colors can be produced and delivering a much improved viewer experience.

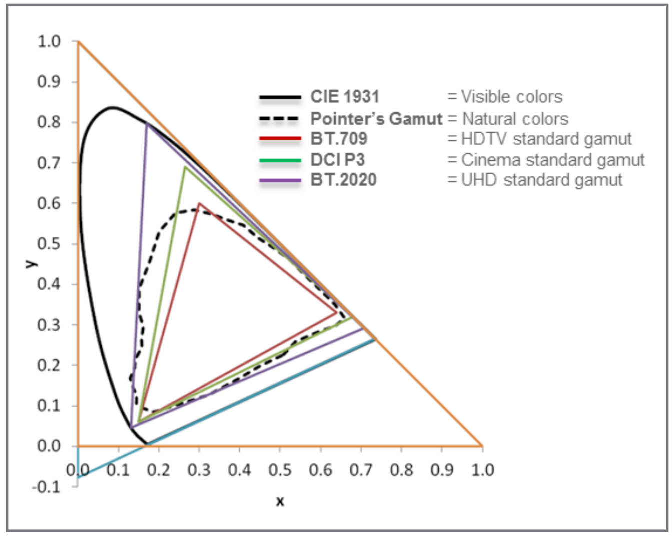

Figure 2 – Comparison of different color gamut.

Specific Requirements for Live HDR

As explained above, HLG and SMPTE ST 2084/PQ are standardized for HDR productions and international program exchange.

Non-live file-based workflows allows using 12-bit, 14-bit or even 16-bit to deliver RAW or LOG signals with the best possible performance and with a large headroom into the post production. Since inside the post production a higher bit depth is available as required for the output signals, any conversions can be done without limiting the image quality.

Any live production workflow available today is limited to signals with 10-bit depth. This means in live productions conversion between different HDR production formats needs to be done in the 10-bit domain. Converting one 10-bit format into another 10-bit format will reduce the performance and the headroom of the signal and should be avoided whenever possible and the use of native HDR signals throughout the full production is highly recommended.

The question which of the two formats should be used for a given application cannot be answered in this whitepaper. Both formats have their strengths and their limitations, and which one offers the better compromise depends on the specific conditions of the production. But since HLG and PQ use the bit range available in a different way (see Figure 3), conversion between them would add the limitations from both systems to each other. The same is true if any other than the two standardized systems is used as an inbetween production format and must be therefore avoided.

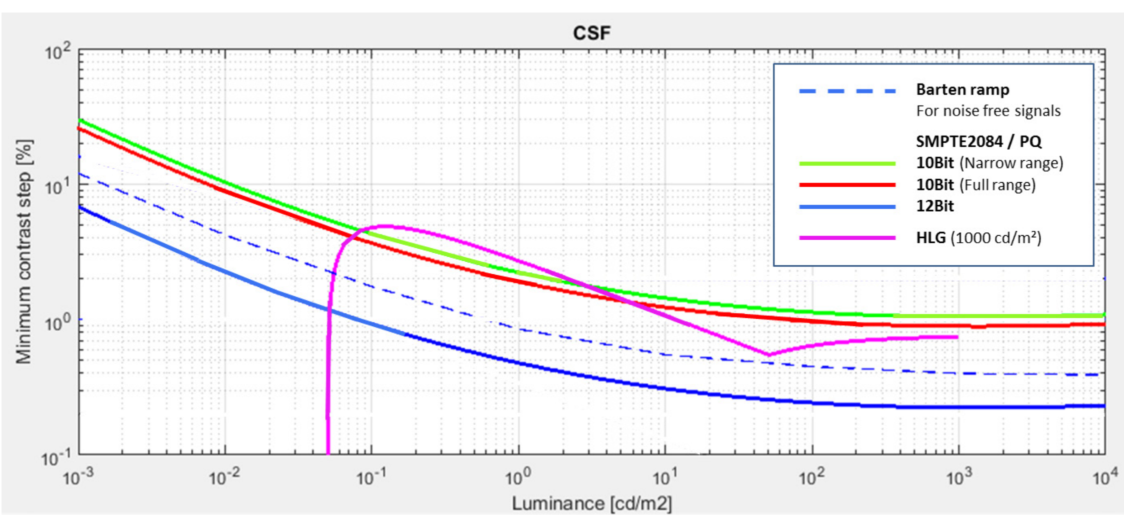

Figure 3 – Comparing the potential visibility of banding errors for different HDR curves.

Another challenge to live HDR productions is that an artistic control of the look of the images is requested by users. This became clear from the first live HDR test productions back in 2014 where the vision engineers asked for ways to modify the look of the HDR images. A new set of controls have been implemented in the latest HDR-capable cameras which allows modifying the HLG or PQ curves to achieve a certain look to the image (see Figure 4).

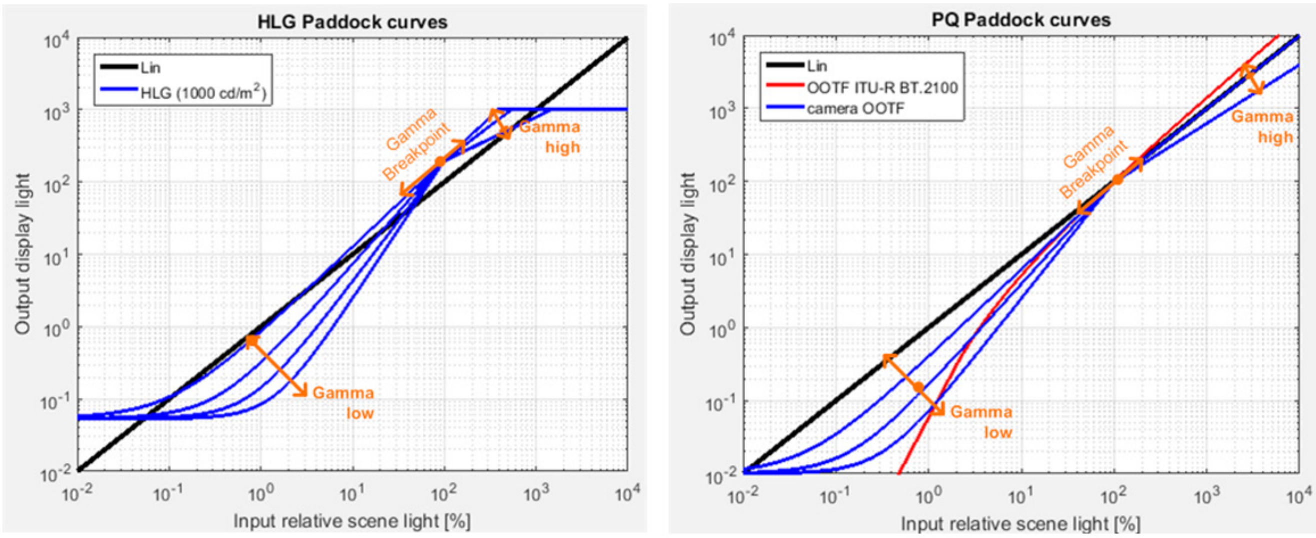

Figure 4 – Artistic control for HLG and PQ.

If the specified HDR curve is modified after the output of the camera (which means in the 10-bit domain), it would reduce the headroom of the signal. Therefore it is important that the HDR workflow selected allows having these functions inside the camera head where a much larger bit depth is available, preserving the full native 10-bit HDR performance (see Figure 5).

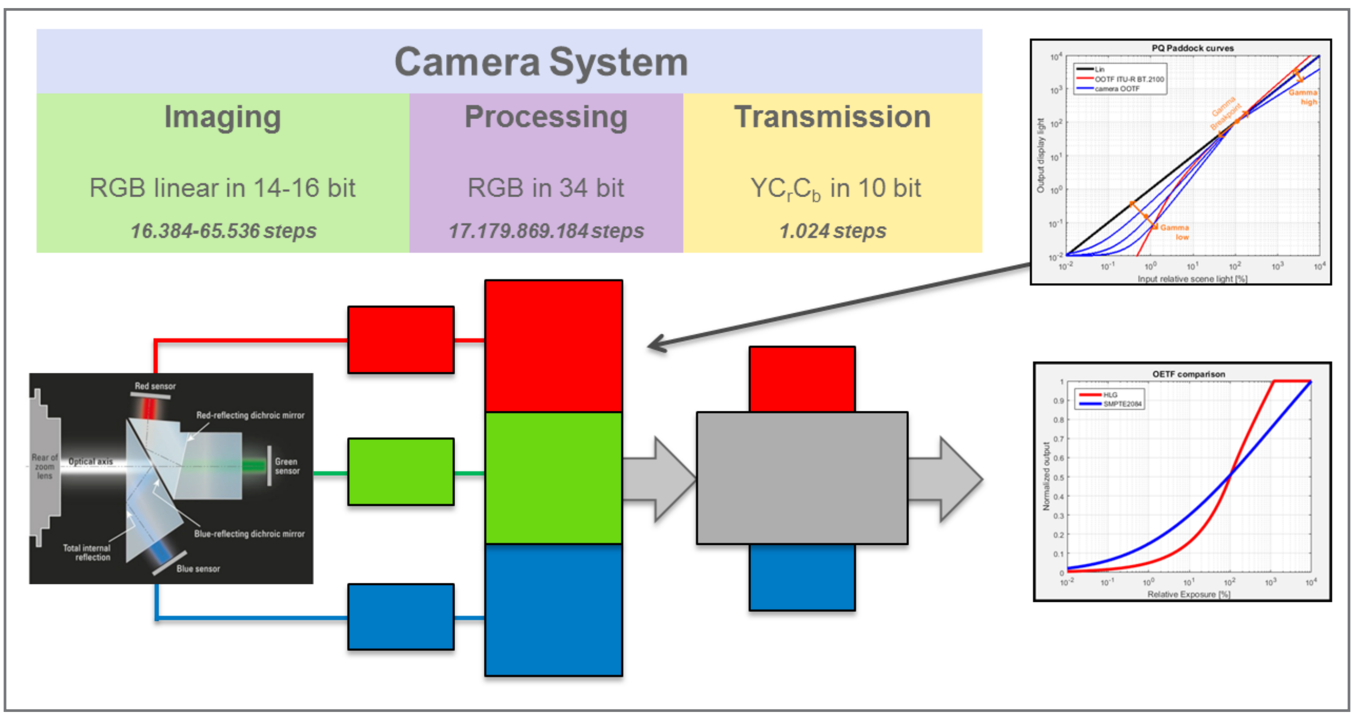

Figure 5 – Workflow diagram for native HDR operation with artistic control inside the camera head.

HDR/SDR Compatible Workflows

A full parallel HDR and SDR workflow is the easiest way to produce both HDR and SDR at the same time, from a single camera system through the full production chain (see Figure 6).

In a full parallel scenario, the camera delivers two simultaneous signals, one HDR and one SDR. In this simultaneous HDR and SDR production workflow, the camera lens iris is set to HDR output and the SDR gain is used to control the SDR output to the required level. As long as the scene lighting does not change significantly, the lens iris will not need to be changed and a moderate variation of the lighting condition will be well inside the headroom of the HDR output.

In comparison, SDR does not offer this additional headroom, so a much more precise adaptation of the sensitivity will be required. Challenges in this workflow include the simultaneous shading of HDR (which requires less work due to the higher dynamic range) and SDR signals (which requires more work due to the limited dynamic range) as well as the handling of both signals separately through the full production chain. This translates into a more complex and expensive workflow which might be accepted for certain applications and/or for an intermediate period of time, but might not be acceptable in the long term. It's akin to the early days of HD, when remote sports productions would use separate SD and HD trucks and crews.

An alternative to the full parallel HDR/SDR workflow is to use only native HDR signals from the camera and then perform an HDR-to-SDR conversion somewhere during the production. While this simplifies the workflow and reduces the amount of resources required, in contrast to the parallel HDR/SDR workflow, there is no separate control for the SDR and HDR outputs, and the SDR gain cannot be independently controlled from the HDR signal. As a result, the success depends on the quality of the HDR-to-SDR conversion under all types of lighting conditions.

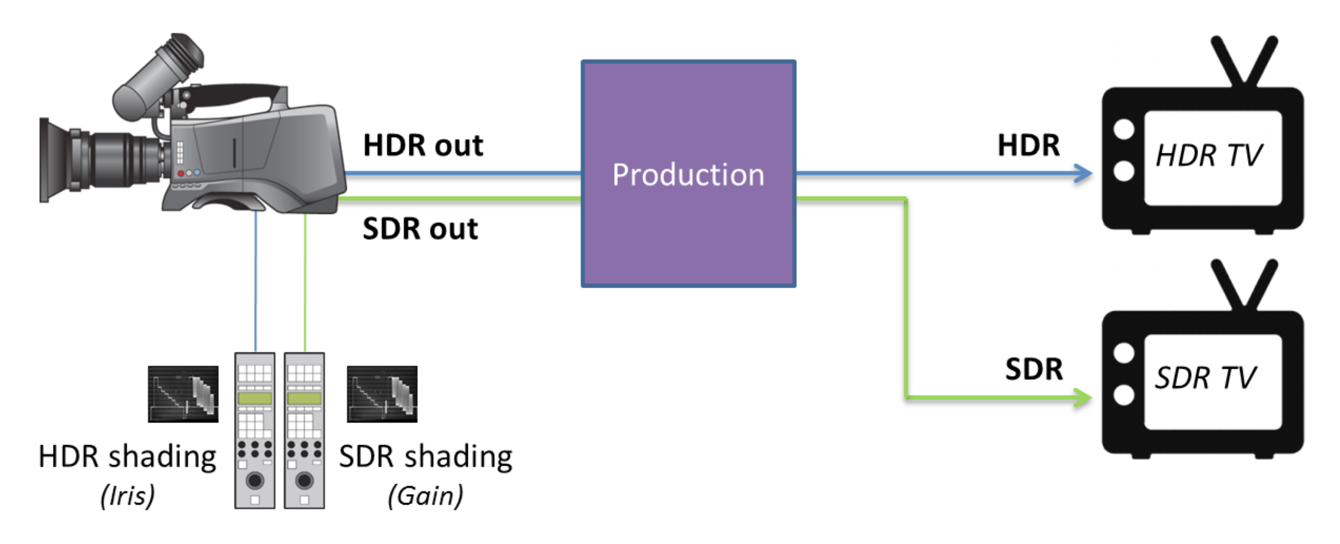

Figure 6 – Parallel HDR and SDR workflow.

Static Conversions vs. Dynamic Conversion

Broadcasters and content creators planning to add HDR to their workflows have two types of HDR-to-SDR conversions to consider: static conversions with a fixed LUT or a selectable LUT (the "look up table" that is the template for the conversion), and dynamic conversions that analyze the picture content and apply content-based settings.

Static conversion offers always predictable results and allows controlling the offset between the SDR and HDR depending on the users' requirements. On the other hand there will be limitations especially during very challenging lighting conditions to get the best SDR and HDR outputs at the same time.

Dynamic conversion appears to offer a larger capability of processing inside the production chain, although automatically adopting the look of the image might not be acceptable for all users or in all cases.

Versions of both types of converters are available today and initial testing in live environments continues to deliver very promising results. No doubt a variety of solutions are available today and even more will become available in the near future covering a wider range of typical live applications.

Optimized HDR/SDR Compatible Workflow for Live Broadcast

For the best results under the widest range of production environments, Grass Valley recommends a native HDR workflow where SDR is derived by conversion (see Figure 7).

Which signal to be used for camera shading depends on the type of conversion and more details can be found in the following Operational Aspects section.

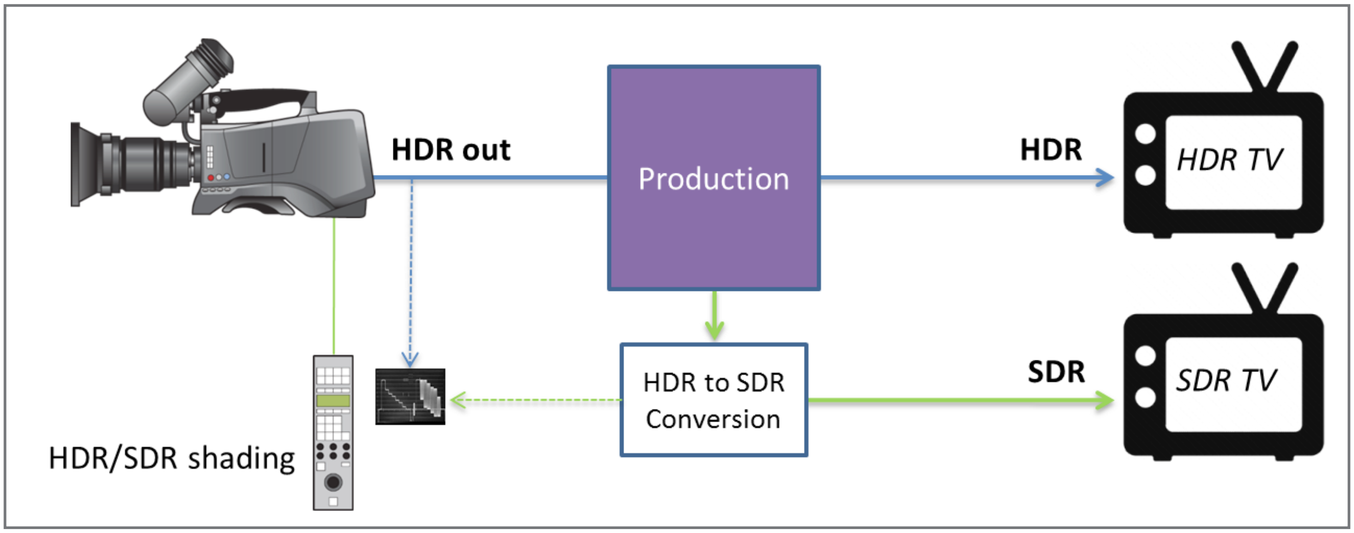

Figure 7 – Native HDR workflow with SDR derived by conversion.

Which signal must be used for the camera shading depends on the type of conversion. More details can be found in the operational aspects section below.

Signal Conversion

With the Densité XIP-3901 processing platform and the XIP-3901-UC, XIP-3901-DC and XIP-3901-FS applications from Grass Valley, a Belden Brand, an ultra-flexible solution for multiformat productions is available. The XIP-3901 can up/downconvert between HD, 3G and 4K UHD and at the same time converts between SDR and HDR and between BT.709 and BT.2020 color gamut with the XIP-3901-UDC-HDR processing option. (see Figure 8).

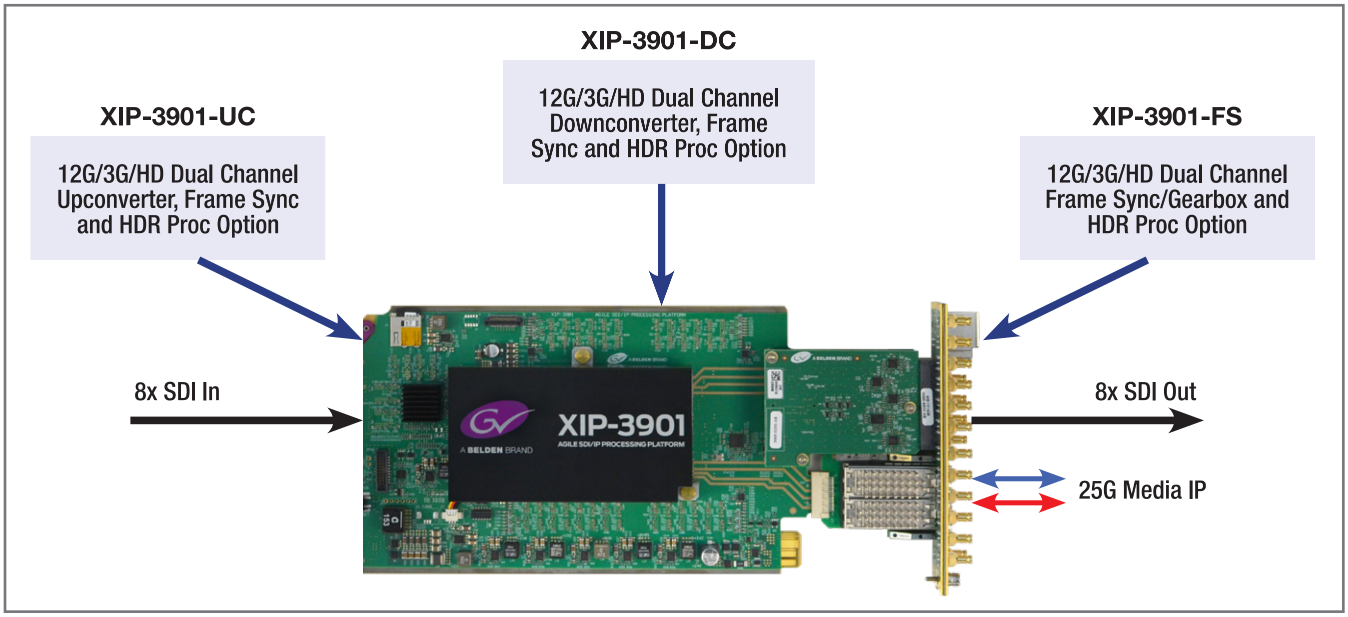

Figure 8 — XIP-3901 agile processing platform with software options.

The XIP-3901 processing card can handle two UHD signals and up to 12 XIP-3901 cards can be equipped into one 4 RU size Densité 3+ chassis (see Figure 9), which means up to 24 4K UHD signal conversions require only 4 RU of space.

The up/downconversion capabilities between the different video formats can be found in the Figure 10 below.

Figure 9 — Densité 3+ chassis.

APPLICATIONS: Input Format \ Output Format	XIP-3901-UC 720p50/59	XIP-3901-UC 1080i50/59	XIP-3901-UC 1080p50/59 A	XIP-3901-UC 1080p50/59 B DL	XIP-3901-UC 2160p50/59 Mode 1	XIP-3901-UC Quad Link 3G 50/59 A	XIP-3901-UC Quad Link 3G 50/59 B	XIP-3901-DC 720p50/59	XIP-3901-DC 1080i50/59	XIP-3901-DC 1080p50/59 A	XIP-3901-DC 1080p50/59 B DL	XIP-3901-DC 2160p50/59 Mode 1	XIP-3901-DC Quad Link 3G 50/59 A	XIP-3901-DC Quad Link 3G 50/59 B	XIP-3901-FS 720p50/59	XIP-3901-FS 1080i50/59	XIP-3901-FS 1080p50/59 A	XIP-3901-FS 1080p50/59 B DL	XIP-3901-FS 2160p50/59 Mode 1	XIP-3901-FS Quad Link 3G 50/59 A	XIP-3901-FS Quad Link 3G 50/59 B
720p50/59			●	●	●	●	●								●						
1080i50/59			●	●	●	●	●									●					
1080p50/59 A			●	●	●	●	●	●	●	●	●						●	●			
1080p50/59 B DL			●	●	●	●	●	●	●	●	●						●	●			
2160p50/59 Mode 1								●	●	●	●								●	●	●
Quad Link 3G 50/59 A								●	●	●	●								●	●	●
Quad Link 3G 50/59 B								●	●	●	●								●	●	●

Figure 10 — Video format conversion table.

The color space and HDR conversion options can be found in Figure 11 below.

XIP-3901 Application	XIP-3901-UC		XIP-3901-DC		XIP-3901-FS		
Video Format	**3G to UHD**	**HD to UHD/3G**	**UHD to 3G**	**UHD/3G to HD**	**UHD to UHD**	**3G to 3G**	**HD to HD**
SDR to HLG BT.2100 (BT.2020)	✔	✔	✔		✔	✔	
SDR to PQ ST.2084 (BT.2020)	✔	✔	✔		✔	✔	
HLG BT.2100 (BT.2020) to SDR	✔		✔	✔	✔	✔	
PQ ST.2084 (BT.2020) to SDR	✔		✔	✔	✔	✔	
PQ ST2084 (BT.2020) to HLG BT.2100 (BT.2020)	✔		✔		✔	✔	
HLG BT.2100 (BT.2020) to PQ ST.2084 (BT.2020)	✔		✔		✔	✔	
S-Log3/S-Gamut3 to BT.709 8000%	✔		✔	✔	✔	✔	
S-Log3/S-Gamut3 to HLG BT.2100 (BT.2020)	✔		✔		✔	✔	
S-Log3/S-Gamut 3 to PQ BT.2100 (BT.2020)	✔		✔		✔	✔	

Figure 11 — Color space and HDR conversion options.

Because of the outstanding flexibility of the XIP-3901 processing platform, only one type of hardware board (see Figure 12) is required — providing any kind of input and output format conversion between different video production formats, different color gamuts and different HDR formats as well as SDR (see Figure 13).

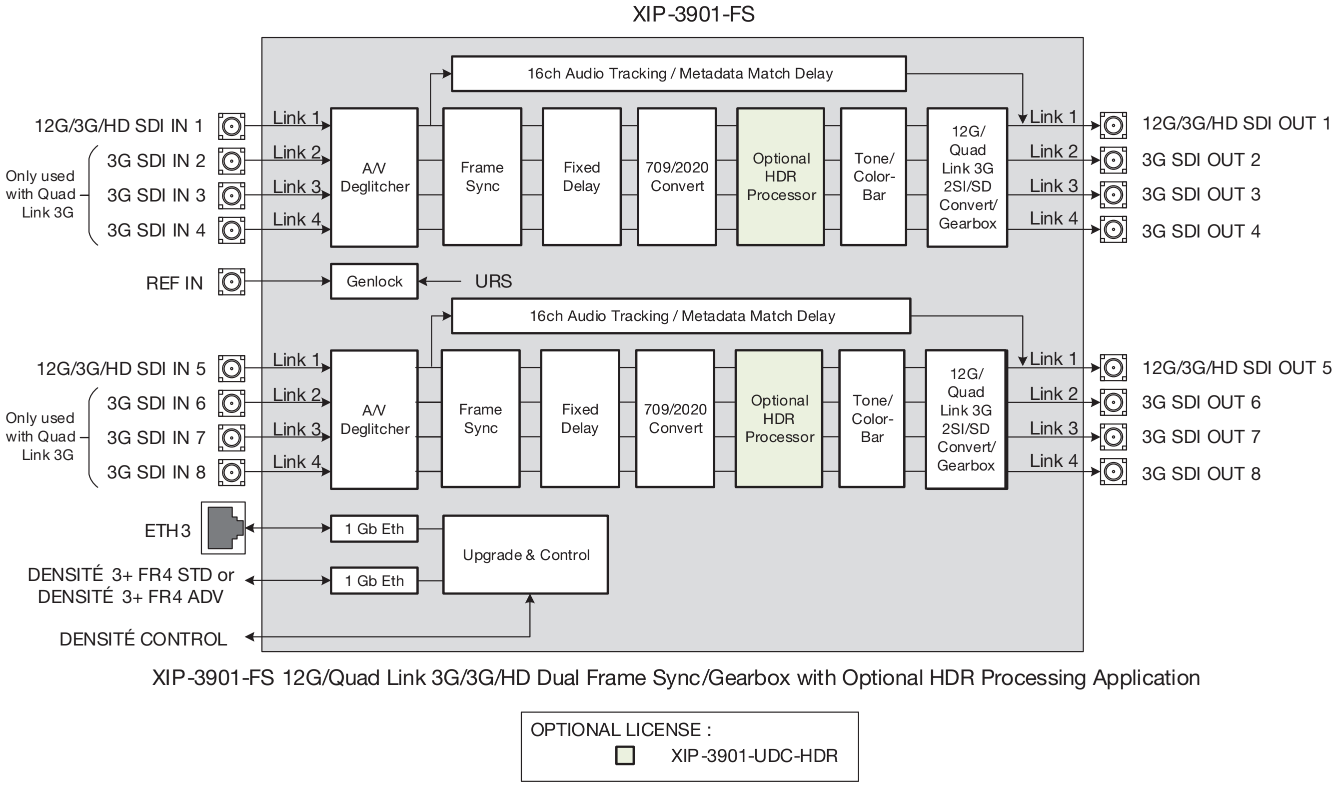

Figure 12 — XIP-3901 functional block diagram.

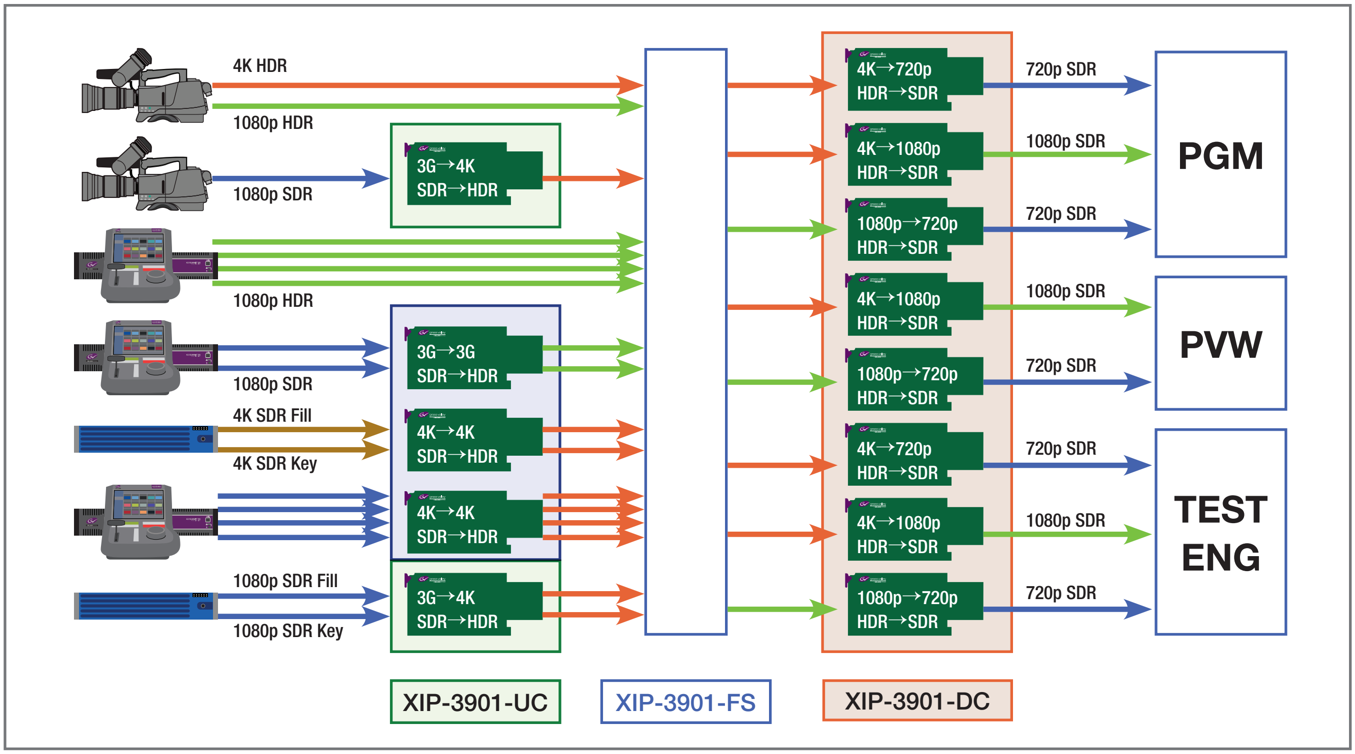

Figure 13 — Video format and HDR format flexibility.

Operational aspects

Before preparing an HDR production, a few things need to be cleared up front:

- Which version of HDR is requested, HLG or PQ?
  - If PQ will be used, what is the clip level, 500 – 10,000 Nits?
    - » ***Typically it's set to 10,000 Nits.***
  - If HLG will be used, what is the SDR set point, 50% or 75%?
    - » ***After latest changes to the recommendations, it's typically 75%.***
- What color gamut is requested, BT.709 or BT.2020?
  - » ***Typically it's BT.2020 for HDR productions.***
- What luminance and color difference signal representation is requested?
  - » ***Typically YCbCr is used.***
- What code value range is requested, narrow or full?
  - » ***For most live applications, it's narrow.***
- What kind of SDR downmapping is requested, static or dynamic?
  - » ***Depending on the downmapping, shading needs to be done on HDR or SDR (see Figure 14).***

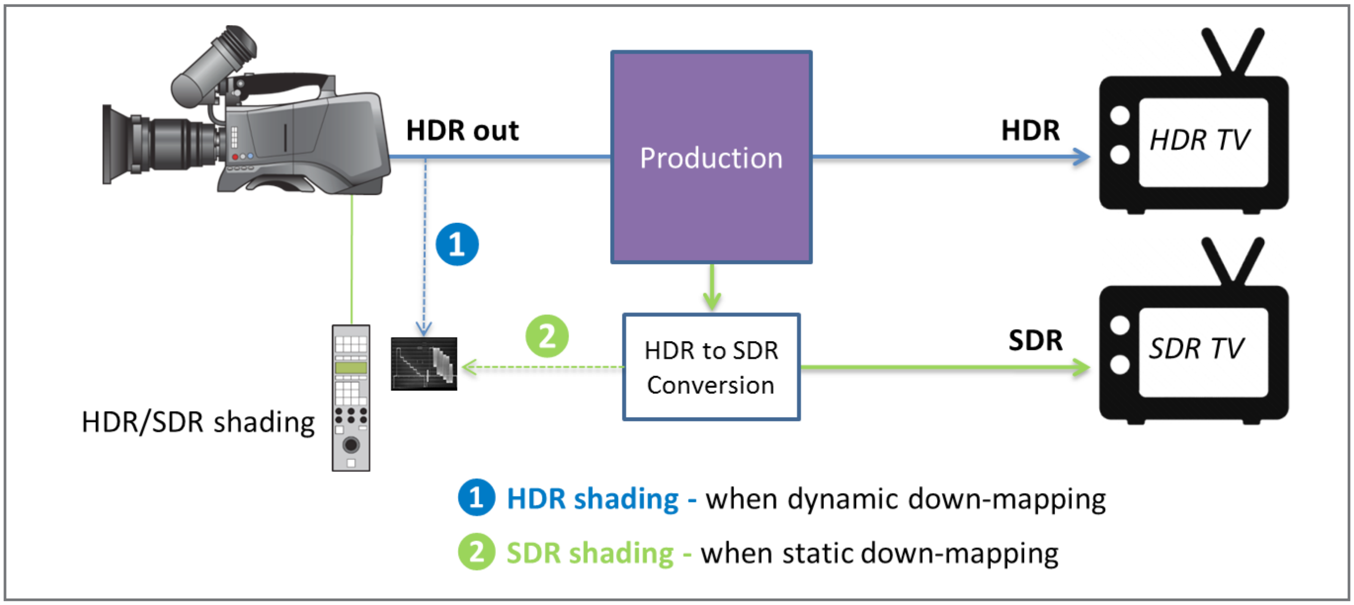

Figure 14 – Optimum camera shading depending on the HDR/SDR downmapper.

In most cases, at least for the time being, not all sources will be able to deliver the signal formats as required for the production. Since HDR and SDR or PQ and HLG or BT.709 and BT.2020 color gamut are not compatible, all signals have to be up/downmapped to the selected production format layer (see Figure 15).

Quite a large number of up/downmappers might be required and the requirements must be carefully calculated upfront for an HDR production to avoid any shortage. In addition, it is highly recommend to always keep a few channels of up/downmappers on spare for unexpected requirements.

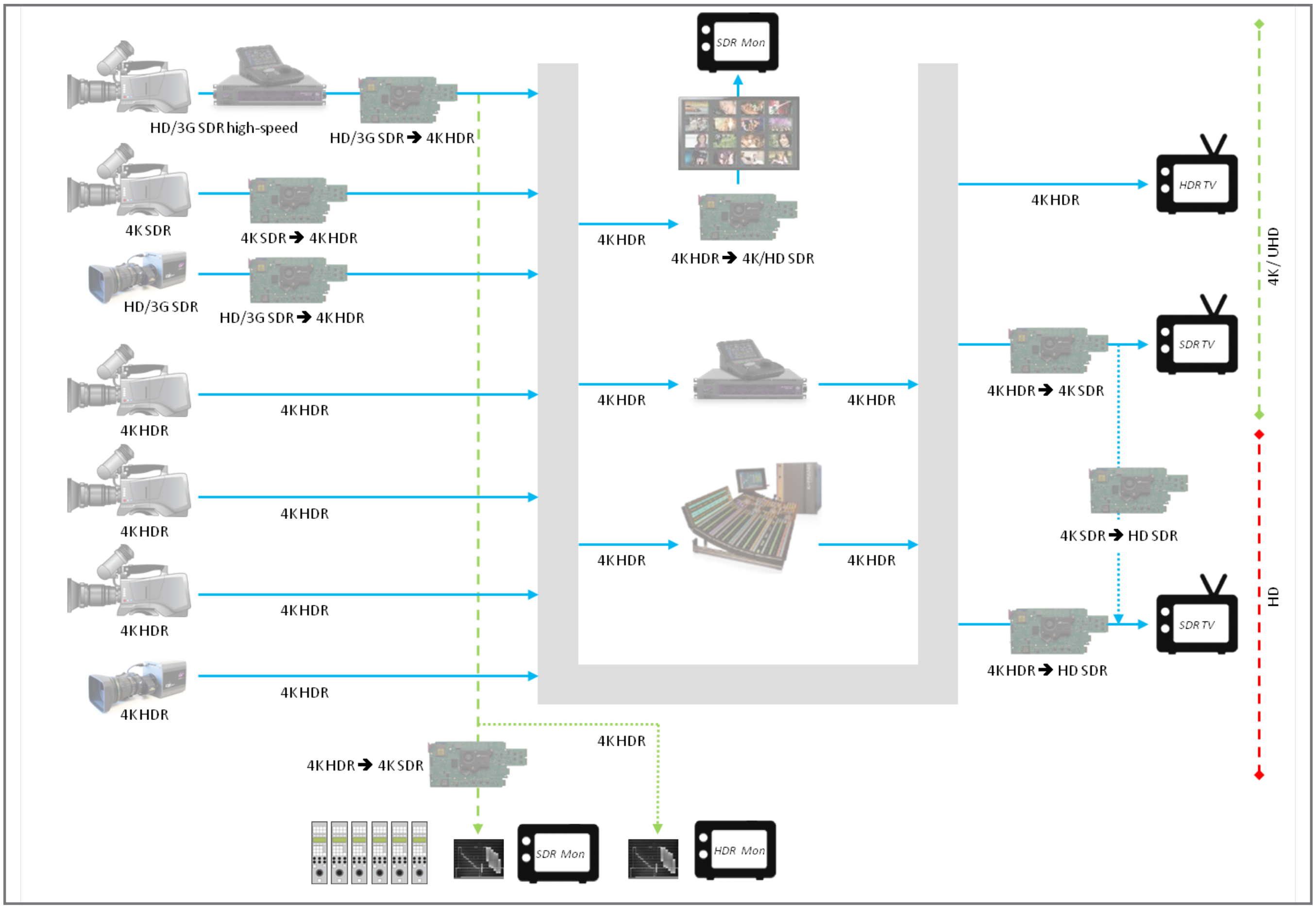

Figure 15 – Typical HDR/SDR production workflow with upmapping and downmapping.

Conclusion

HDR is shaping up to be the next major advancement in the viewing experience, with consumers praising the image improvements and broadcasters working to find the best options for delivery. Grass Valley's HDR solutions allow our customers to choose the best approach for their specific production needs today, whether that be HD, 4K UHD or both, through an easy upgrade path with GV-eLicense if today's business model demands HD.

Grass Valley, a Belden Brand, offers a portfolio of HDR-enabled solutions that includes cameras, switcher frames, servers, routers, up/downmapping cards and multiviewers. With these devices, broadcasters are able to produce native 10-bit HDR in either HD or 4K UHD and deliver that content in HDR and SDR simultaneously, as necessary, thanks to the high-quality conversion that can be done with a downmapping process. Additionally, these solutions provide native support for both of today's worldwide standard: Hybrid Log-Gamma (HLG) and Perceptual Quantization (PQ or SMPTE ST 2084).