Grass Valley

WHITEPAPER

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

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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

High Dynamic Range (HDR) is gaining widespread consumer adoption due to its ability to deliver a visibly wider dynamic range, with brighter highlights, deeper shadows, and more accurate color reproduction. By offering a contrast ratio that more closely reflects real-world viewing conditions, HDR enables image reproduction that is significantly closer to human visual perception. In addition, HDR provides more consistent and reliable results in challenging acquisition environments — such as uneven lighting, high-contrast scenes, or partial shade — commonly encountered in outside broadcast productions. A further advantage of HDR is its format independence, as it does not require specialized viewing environments to clearly demonstrate its benefits.

For broadcasters and content creators, adopting an HDR workflow introduces a number of technical and operational challenges. Chief among these is the requirement for a parallel SDR/HDR production workflow, in which signals must be flexibly adapted through up-mapping and down-mapping processes. This enables the seamless integration of mixed-format sources and outputs without compromising image quality. Typical use cases include incorporating legacy SDR content into HDR productions, or distributing HDR content to SDR multiviewers and monitoring systems within the studio. In all cases, preserving the producer's creative intent for each individual signal is critical.

This white paper examines the key challenges and optimal solutions for producing native 10-bit HDR content in both HD/3G and 4K UHD formats, while enabling simultaneous HDR and SDR delivery. This is achieved through high-quality conversion and down-mapping processes that ensure consistent image quality across formats. The solutions discussed provide native support for both globally adopted HDR standards: Hybrid Log-Gamma (HLG) and Perceptual Quantization (PQ, SMPTE ST 2084).

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HDR Standards

The ITU Radiocommunication Sector (ITU-R) published Recommendation ITU-R BT.2100 in 2017, defining "Image parameter values for high dynamic range television for use in production and international programme exchange". The most recent revision, ITU-R BT.2100-3, was released in February 2025.

Recommendation ITU-R BT.2100 specifies the HDR-TV image parameters for production and international programme exchange using the Perceptual Quantization (PQ) transfer function, as defined in SMPTE ST 2084, and the Hybrid Log-Gamma (HLG) transfer function (see Figure 1).

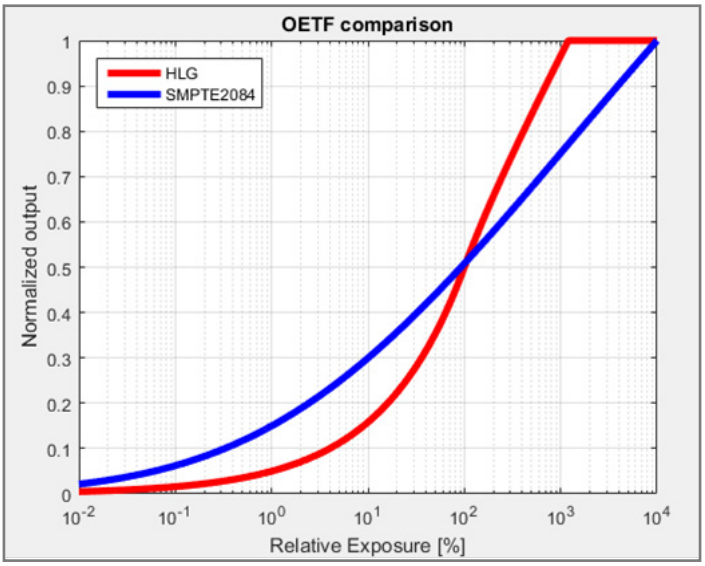


Figure 1 — OETF comparison HLG and SMPTE ST 2084 / PQ.

Recommendation ITU-R BT.2100 states that "for programme production and international exchange of HDR-TV, the perceptual quantization (PQ) or Hybrid Log-Gamma (HLG) specifications should be used," and further emphasizes that HDR television production and display "should make consistent use of the transfer functions of one system or the other and not intermix them."

As a result, PQ and HLG are the only HDR standards specified by ITU-R for live broadcast production and international programme exchange. Other production formats — including manufacturer-specific logarithmic curves or RAW formats commonly used in file-based digital cinematography workflows — are outside the scope of these ITU recommendations. The same applies to consumer distribution, where PQ and HLG are the universally adopted HDR standards. Consequently, any content produced in alternative HDR formats must be converted to either PQ or HLG prior to international programme exchange or distribution to consumer displays.

While non-live, file-based workflows may support higher bit depths (12-bit, 14-bit, or even 16-bit), current live production infrastructures are limited to 10-bit signal processing. This constraint requires that any conversion between HDR production formats in live workflows be performed within the 10-bit domain. Converting between different 10-bit HDR formats can introduce cumulative quantization errors and reduced signal fidelity, and should therefore be avoided wherever possible.

Multiple fully native HDR workflow approaches are available to address these challenges and are 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 reproduction of 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 a much improved viewer experience can be delivered.

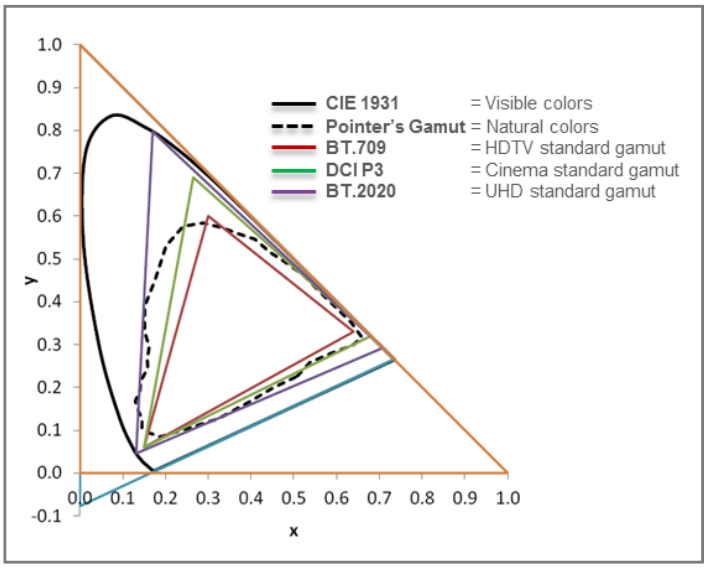


Figure 2 — Comparison of different color gamuts.

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 allow 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 in-between production format and must be therefore avoided.

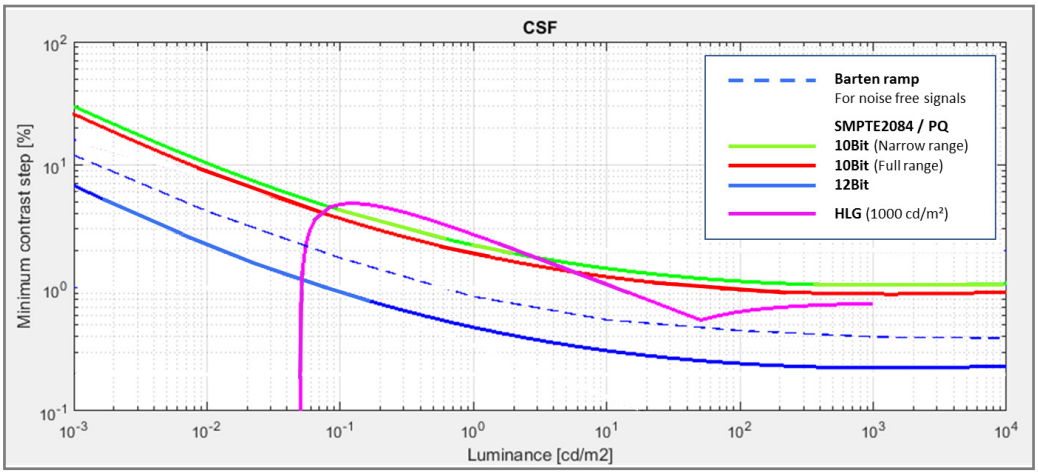


Figure 3 — Comparing the potential visibility of banding errors for different HDR curves.

It should be noted that all current Grass Valley cameras natively support Hybrid Log-Gamma (HLG), SMPTE ST 2084/Perceptual Quantization (PQ), as well as S-Log3 with S-Gamut. While HLG and PQ are recommended for all live production applications, S-Log3 provides an alternative, scene-referred workflow better suited to non-live, file-based production environments.

Another challenge in live HDR production is the requirement for artistic control over the visual appearance of the images. This need became evident during the first live HDR trial productions as early as 2014, when vision engineers requested greater flexibility to adjust and fine-tune the perceived "look" of HDR images.

In response, HDR-capable cameras have been enhanced with additional image control parameters that allow modification of the HLG or PQ transfer characteristics to achieve a desired visual style (see Figure 4).

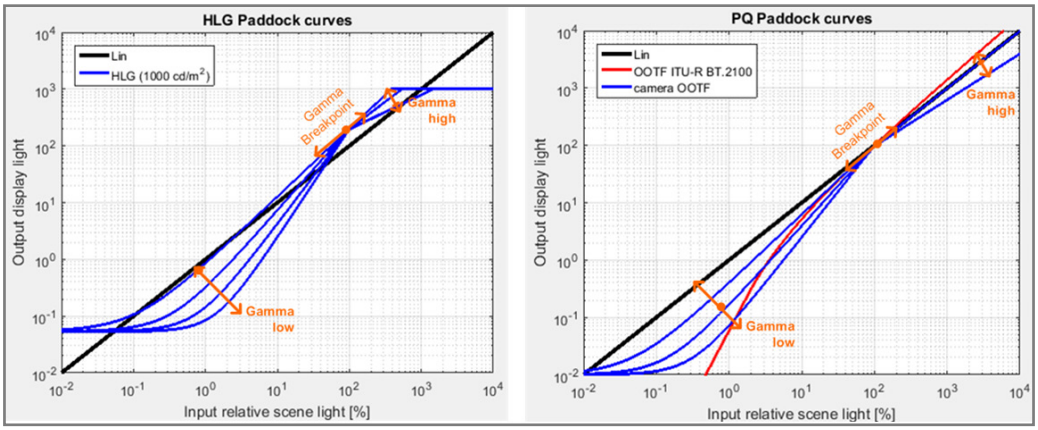


Figure 4 — Artistic control for HLG and PQ.

Furthermore, based on customer feedback, in the current LDX Series cameras from Grass Valley the single Gamma Breakpoint control shown in Figure 4 has been refined and separated into independent Gamma High and Gamma Low breakpoint controls. This enhancement enables the introduction of a linear segment between the two regions, providing increased flexibility and more precise control over highlight and shadow rendering.

As a result, operators can better adapt HDR imagery to creative intent, production requirements, and viewing conditions while maintaining compliance with HDR standards.

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).

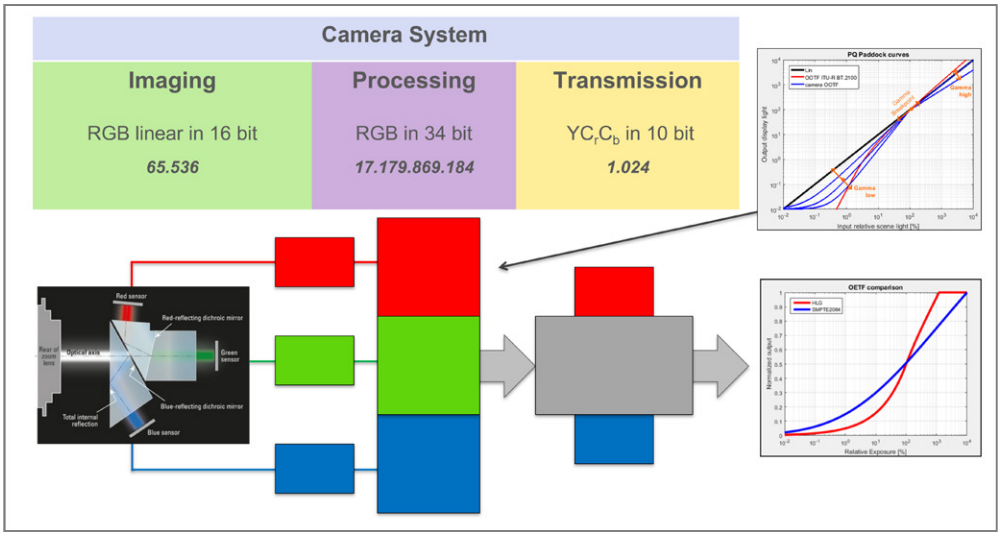


Figure 5 — Workflow diagram for native HDR operation with artistic control inside the camera head.

HDR/SDR Compatible Workflows

A full parallel HDR and SDR workflow is one of the simplest approaches to producing both HDR and SDR outputs simultaneously from a single camera system through the entire production chain (see Figure 6). In this workflow, the camera delivers two concurrent signals — one HDR and one SDR. The camera lens iris is set to optimize the HDR output, while the SDR gain is adjusted independently to achieve the required SDR level. Provided scene lighting does not change significantly, the iris typically remains fixed, and moderate variations in lighting fall well within the HDR headroom.

By contrast, SDR alone lacks this additional headroom, requiring more precise adjustments to sensitivity under the same conditions. Operational challenges in a parallel HDR/SDR workflow include the simultaneous shading of both signals — HDR generally requires less adjustment due to its wider dynamic range, whereas SDR requires more precise control due to its limited range — and the separate management of both signals throughout the production chain. This results in a more complex and resource-intensive workflow, which may be acceptable for specific applications or during transitional periods, but is unlikely to be sustainable long-term. This situation is reminiscent of the early HD era, when remote sports productions often employed 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 (see Figure 7). 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.

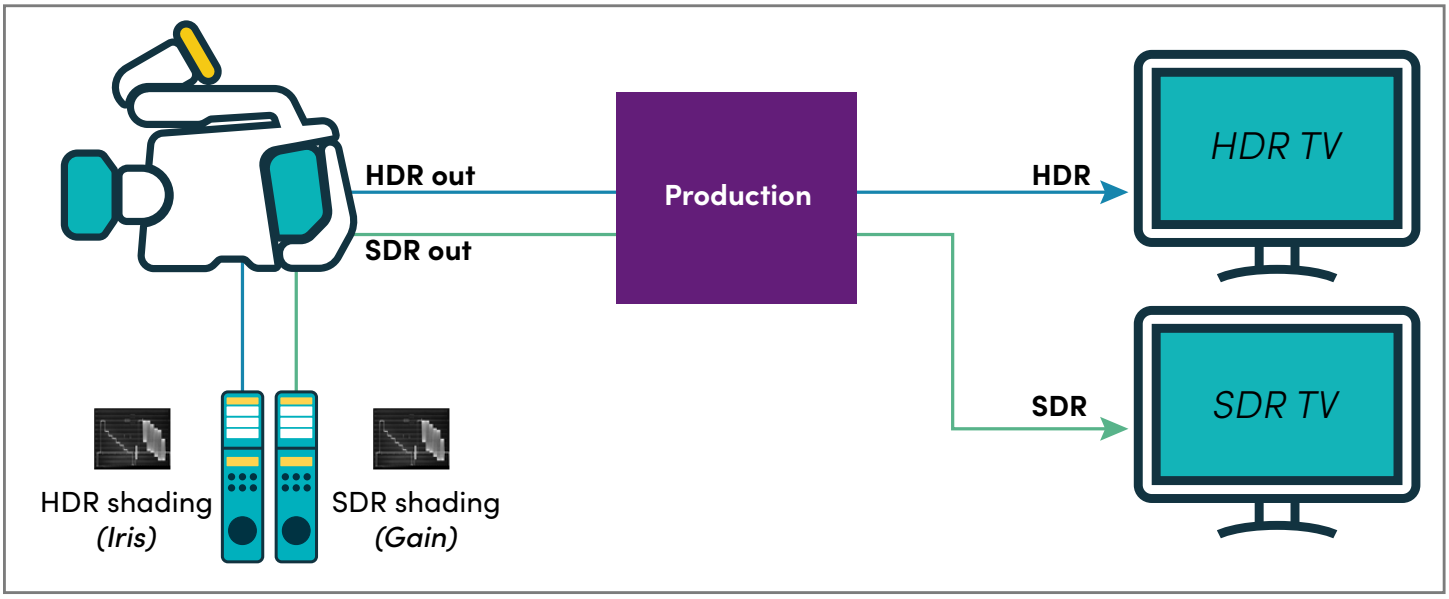


Figure 6 — Parallel HDR and SDR workflow.

Static Conversions vs. Dynamic Conversion

Broadcasters and content creators planning to introduce HDR into their workflows must consider two principal approaches to HDR-to-SDR conversion: static conversion and dynamic conversion. Static conversion relies on a fixed or selectable LUT (Look-Up Table) that defines the transformation between HDR and SDR, while dynamic conversion analyses image content in real time and applies content-dependent processing.

Static conversion provides consistent and predictable results, allowing operators to precisely control the offset and relationship between the HDR and SDR signals according to production requirements. However, this approach has inherent limitations, particularly in scenes with extreme or rapidly changing lighting conditions, where it may be difficult to achieve optimal HDR and SDR representations simultaneously.

Dynamic conversion offers the potential for more sophisticated processing within the production chain by adapting the conversion parameters based on image content. While this can theoretically improve performance in challenging scenarios, the automatic modification of image characteristics may not be acceptable for all productions or creative intents.

Although dynamic converters were initially expected to deliver superior results, their adoption in live broadcast environments has been limited. In practice, 3D-LUT–based HDR/SDR conversion has become the preferred and most widely deployed solution in typical live production workflows today, due to its predictability, transparency, and ease of integration.

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).

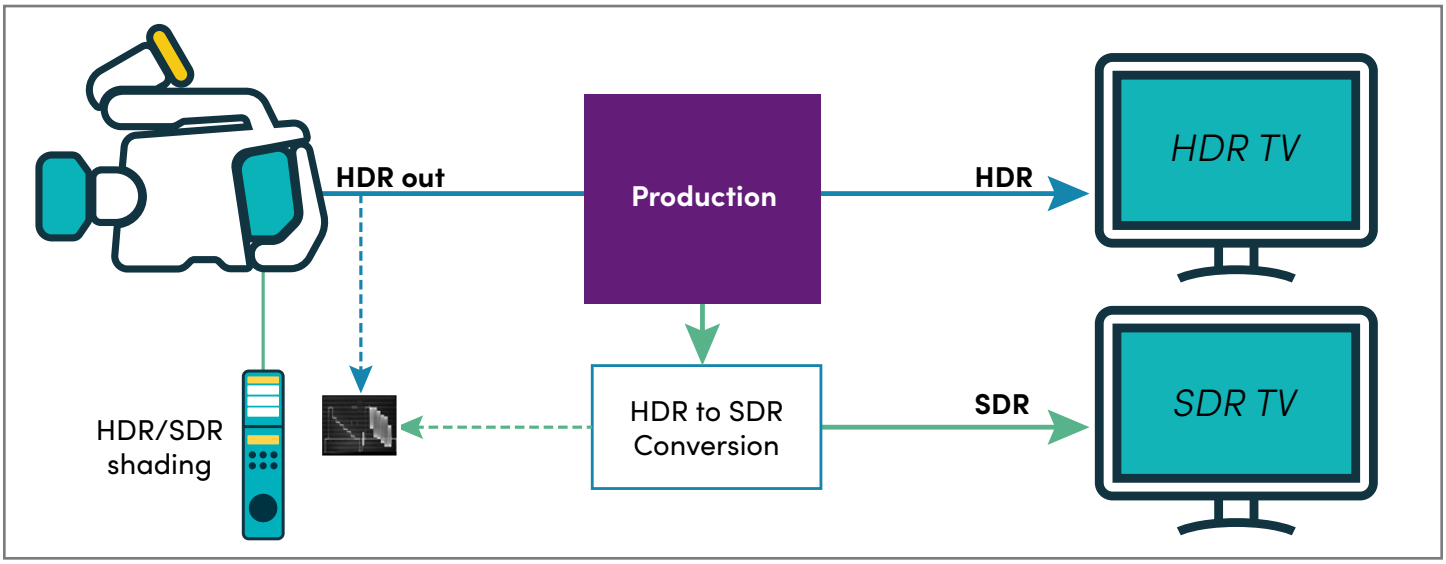


Figure 7 — Native HDR workflow with SDR derived by conversion.

A key differentiator between cameras optimized for simultaneous HDR/SDR live production and those designed for SDR-only or cinema-style applications is the ability to generate and transmit multiple output signals concurrently. Live production workflows frequently require parallel outputs in different resolutions, dynamic ranges, and color spaces to support diverse operational needs. For example, the main program feed may require UHD resolution with HDR and Wide Color Gamut (WCG), while a separate 1080p HDR/WCG feed may be needed for Video Assistant Referee (VAR) systems, and a 1080i SDR/Rec.709 signal is typically required for camera shading and ISO recording (see Figure 8).

The ability to generate all of these signal variants directly within the camera head — rather than exclusively in the camera base station — is essential. This architecture enables full operational flexibility across all camera configurations, including NativeIP operation, compact cameras and 5G- and RF-based wireless, where access to a traditional base station may be limited or unavailable.

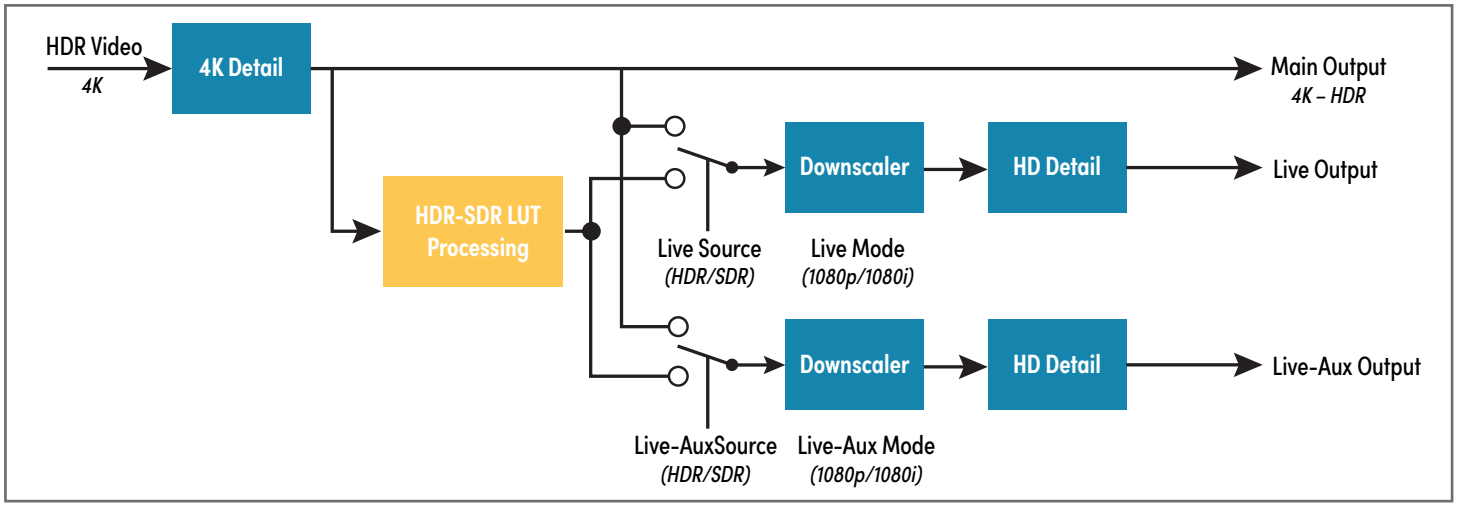


Figure 8 – Multiple outputs selectable at the camera head at LDX 100 Series cameras.

HDR/SDR Camera Control with Integrated 3D-LUT-processing

A critical aspect of live HDR/SDR production is live camera shading—the real-time adjustment of all camera parameters including the new HDR specific look controls, by an operator to ensure consistent image quality across multiple cameras. To support this process, advanced tools have been developed, including dedicated and customizable camera control panels, as well as sophisticated software systems that provide a centralized overview of all cameras and their operating parameters. These tools enable precise, real-time adjustments, ensuring a cohesive visual appearance across the entire production despite varying lighting conditions, camera positions, and camera models.

A well-established operational model, known as closed-loop camera shading, relies on camera shaders monitoring down-mapped SDR signals. For this approach to be effective, the down-mapping characteristics applied at the camera output must precisely match those used throughout the downstream production chain, ensuring consistency in image representation and preserving creative intent (see Figure 9).

If a camera cannot natively provide all required signal variants, external conversion devices must be introduced. This not only increases system complexity and cost but also adds potential points of failure—an especially critical concern in live HDR production environments.

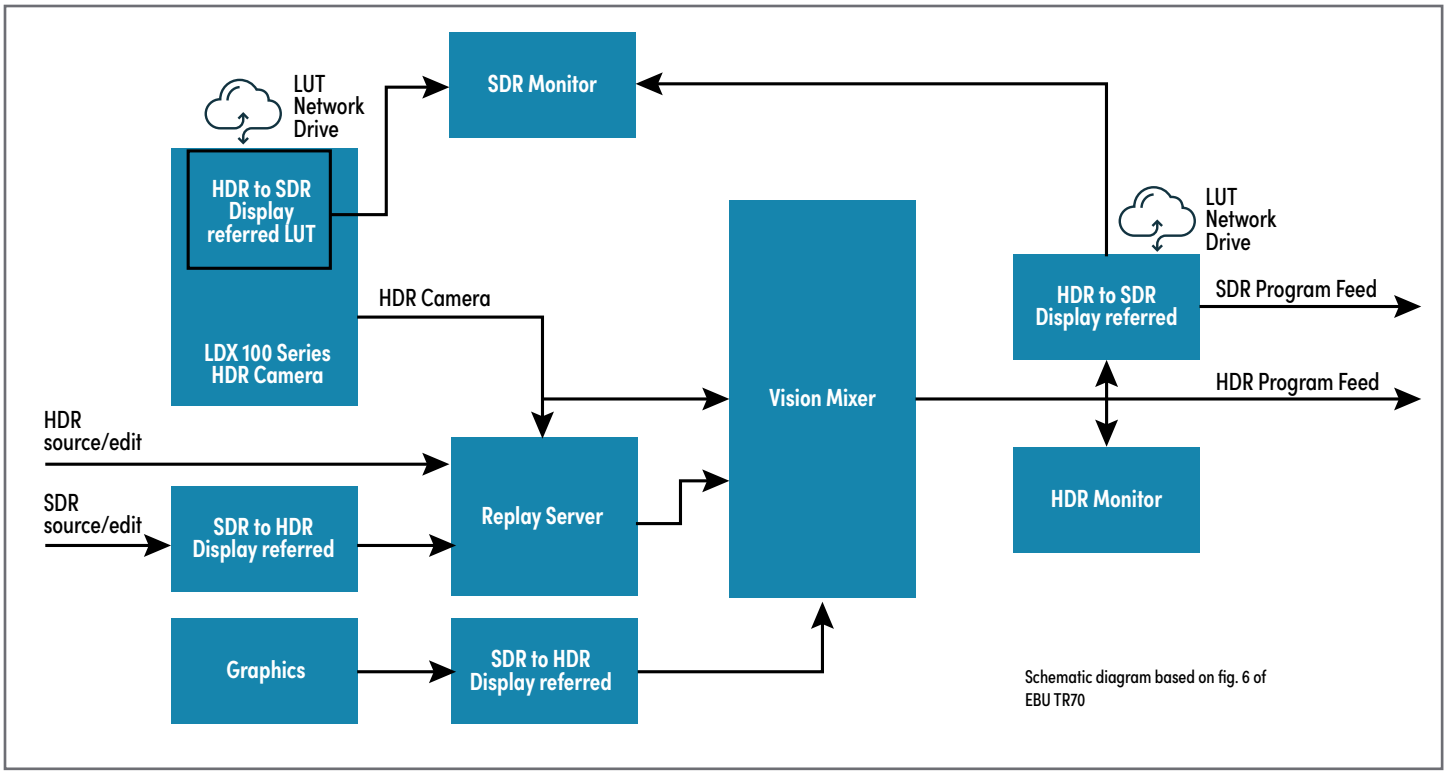


Figure 9 – Closed-loop camera shading

Signal Conversion

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 10).

All current Grass Valley video production switchers support the simultaneous processing of SDR and HDR signals. They can internally convert incoming SDR sources to the selected HDR production format, while also providing down-converted SDR outputs alongside the HDR outputs.

When production switchers do not provide integrated SDR/HDR conversion capabilities, a significant number of external up- and down-conversion devices may be required. In such cases, conversion requirements must be carefully planned and calculated in advance to avoid resource shortages during HDR production. In addition, it is strongly recommended to provision several spare up/down-conversion channels to accommodate unexpected operational needs.

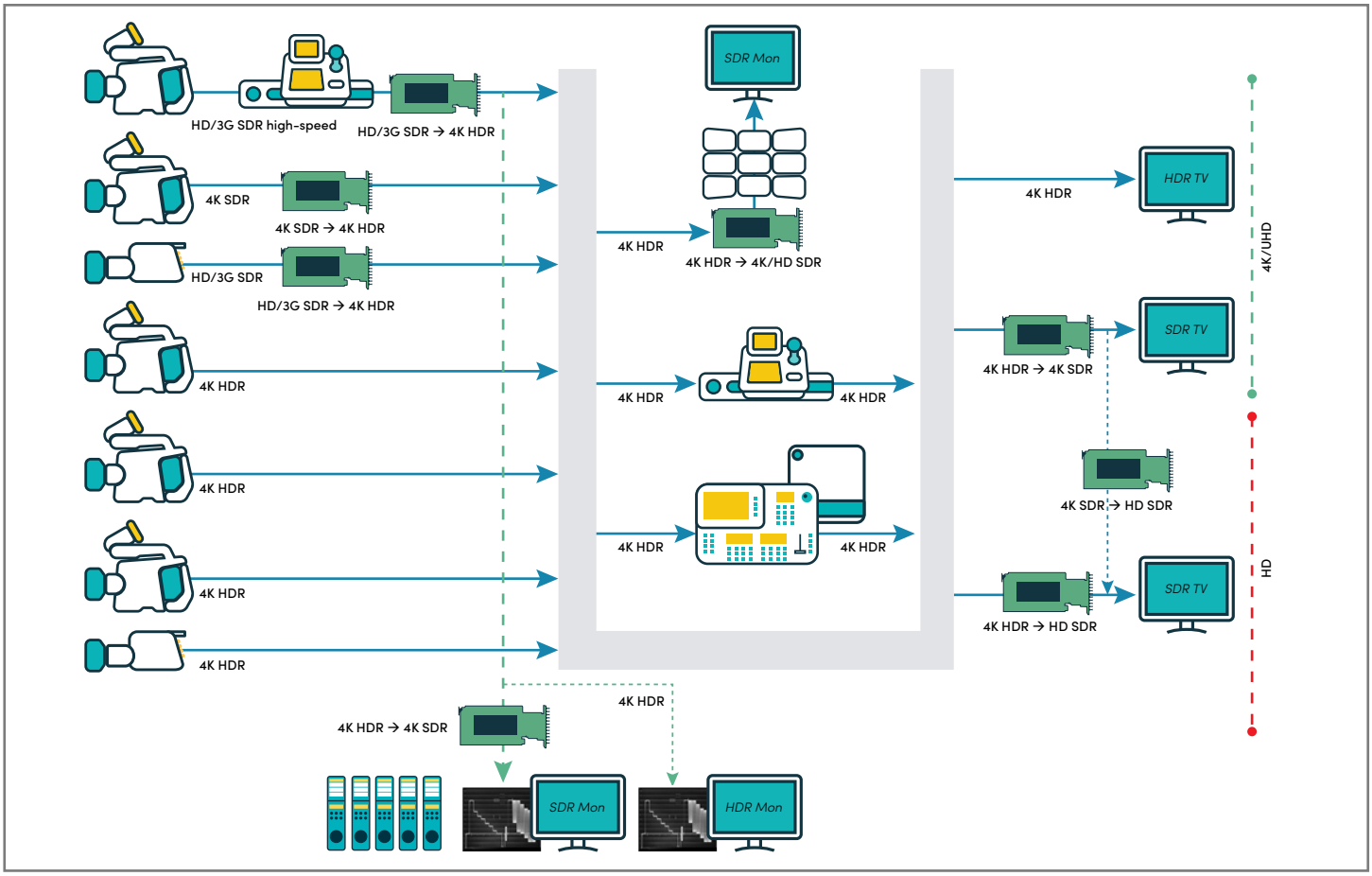


Figure 10 — Typical HDR/SDR production workflow with upmapping and downmapping.

With the Densité XIP-3911 processing platform and the XIP-3901-UC, XIP-3901-DC and XIP-3901-FS applications, an ultra-flexible solution for multiformat productions is available. The XIP-3911 can up/down-convert 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 11).

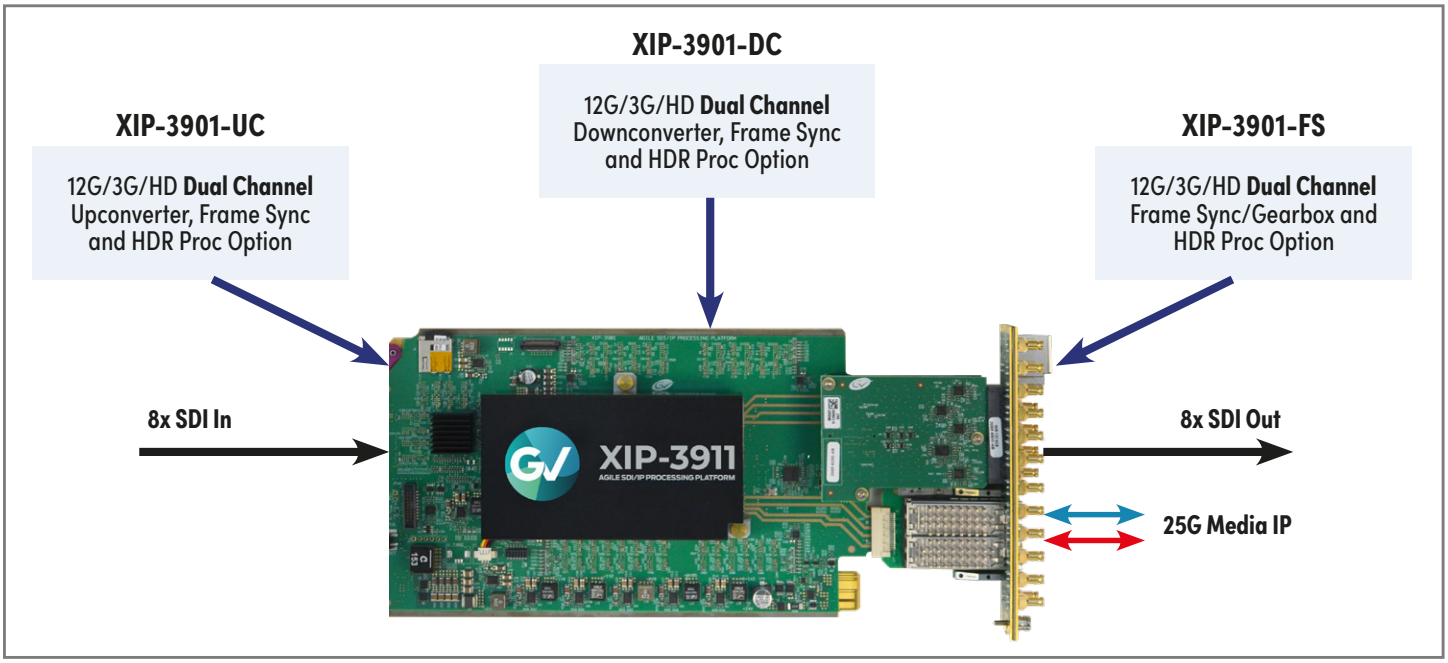


Figure 11 — XIP-3911 agile processing platform with software options.

The XIP-3911 processing card can handle two UHD signals and up to 12 XIP-3911 cards can be equipped into one 4 RU size Densité 3+ chassis (see Figure 12), 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 13 below.

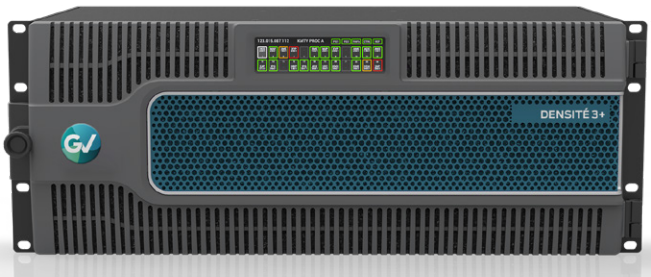


Figure 12 — Densité 3+ chassis.

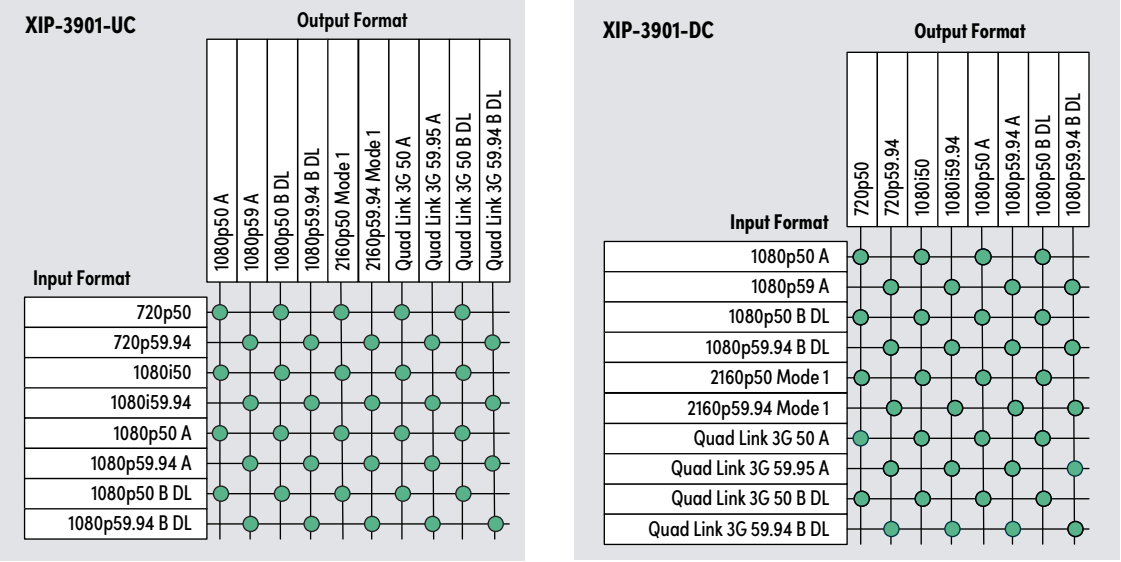
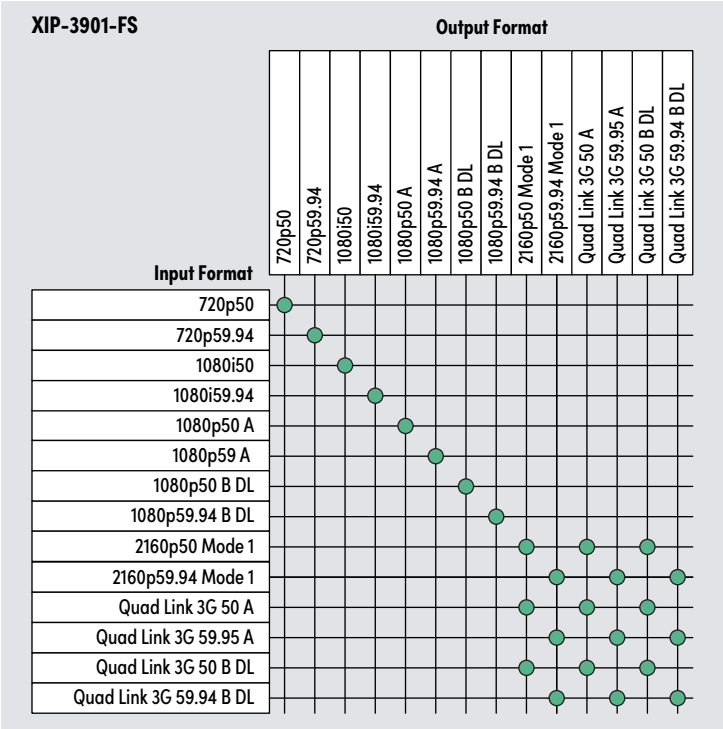


Figure 13 — Video format conversion tables.



The color space and HDR conversion options can be found in Figure 14 below.

XIP-3911 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 14 — Color space and HDR conversion options.

Because of the outstanding flexibility of the XIP-3911 processing platform, only one type of hardware board (see Figure 15) 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 16).

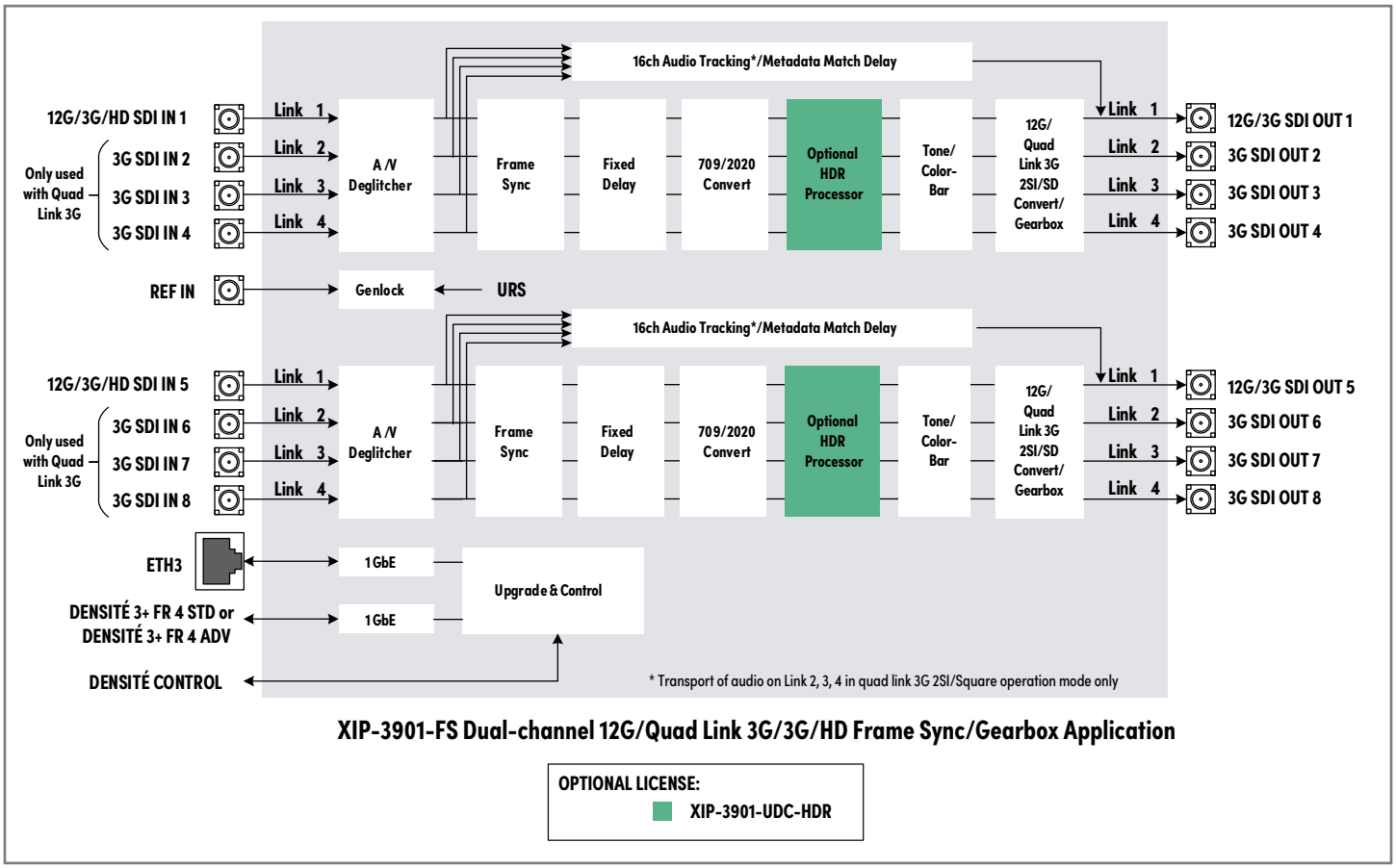


Figure 15 — XIP-3901-FS functional block diagram.

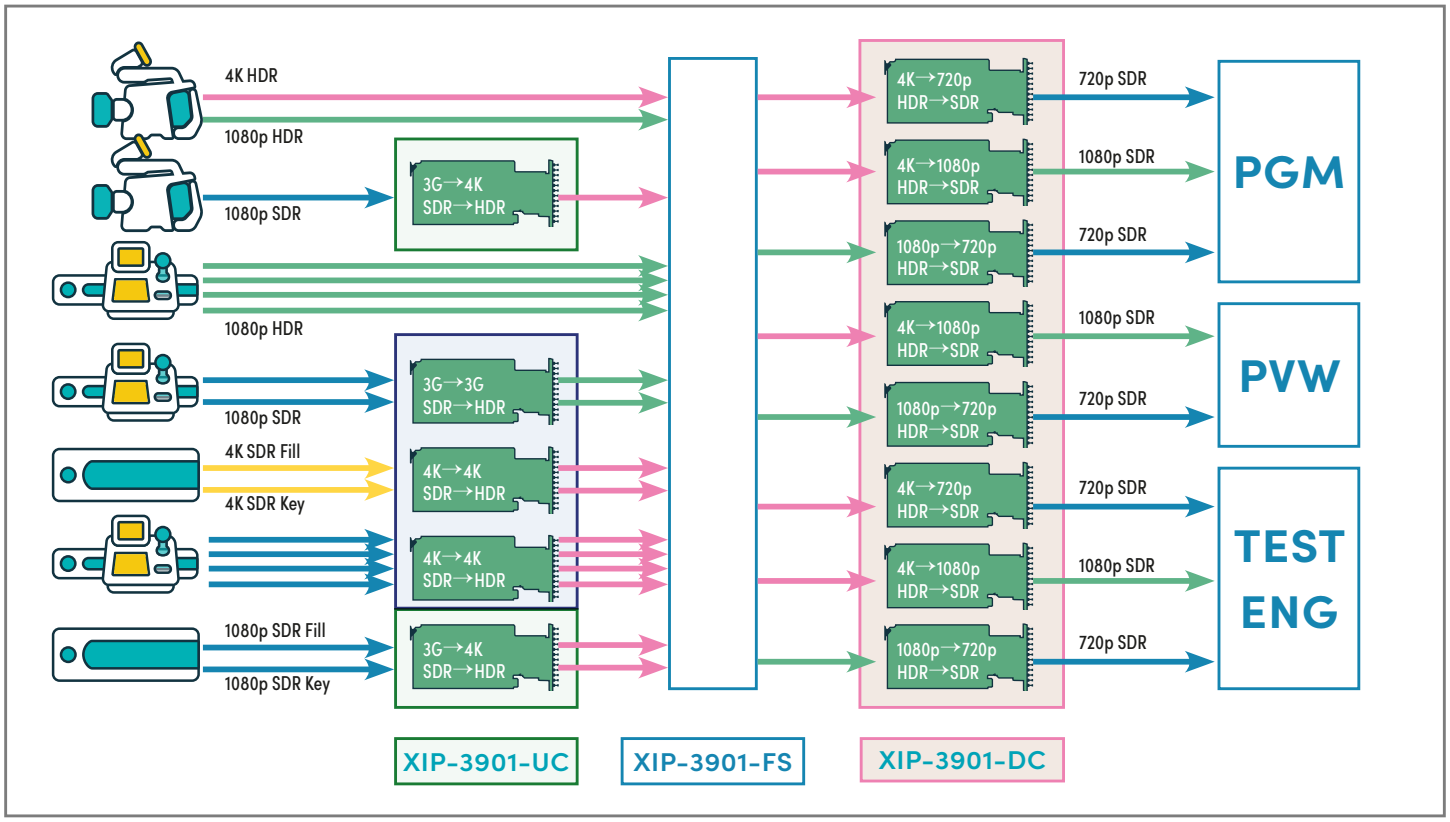


Figure 16 — Video format and HDR format flexibility.

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, 1000 – 10,000 Nits?
  - + Typically it's set to 10,000 Nits.
- If HLG will be used, what is the SDR set point, 73% or 75%?
  - + In most cases it's 73%.

? 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?

- + This might vary case by case.

? 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 17).

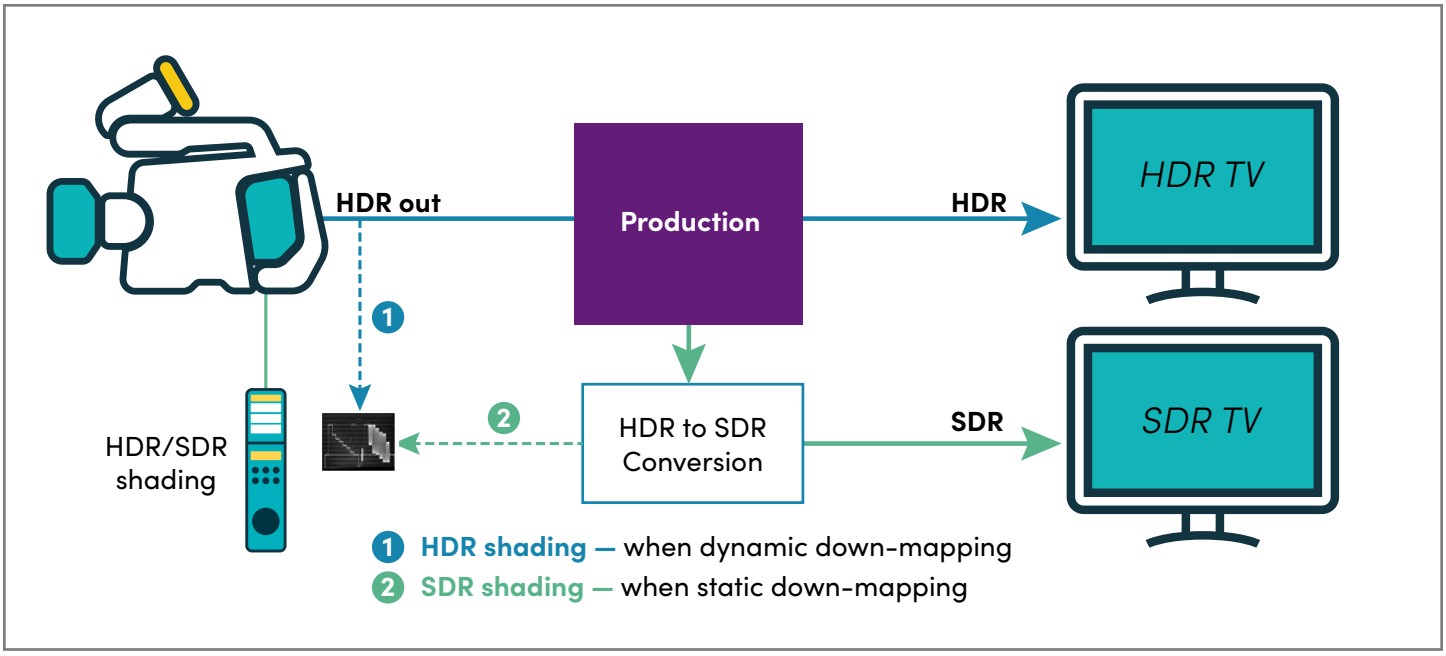


Figure 17 — Optimum camera shading depending on the HDR/SDR downmapper.

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/3G, 4K UHD or both, through an easy upgrade path with GV software options if today's business model demands HD.

Grass Valley offers a portfolio of HDR-enabled solutions that includes cameras, switcher frames, servers, routers, up/down-mapping 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 down-mapping 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).

This product may be protected by one or more patents. For further information, please visit: **www.grassvalley.com/patents**

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