High Dynamic Range Broadcasting

Essential Guide

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Introduction

Television resolutions have increased from the analog line and field rates of the NTSC and PAL systems through HD to the 3840 x 2160 pixels of UHD, with 8K waiting in the wings. However, the dynamic range of the system was very much set by the capabilities of the cathode ray tube, the display device of analog television. The latest displays, LCD and OLED, can display a wider dynamic range than the old standards permit. The quest for better pixels, driven by the CE vendors, video publishers—OTT and broadcast—as well as directors, has led for improvements beyond just increasing resolution.

Following the landmark UHD standard, BT.2020, it was rapidly accepted that to omit the extension of dynamic range was more than an oversight. BT.2100 soon followed, adding high dynamic range (HDR) with two different systems. Perceptual Quantisation (PQ) is based on original research from Dolby and others, Hybrid Log Gamma (HLG) offers compatibility with legacy systems.

Cameras have long been capable of HDR capture. Consumer HDR displays have been around for a few years. It was the intermediate production pipeline that was lacking, all the way through to 8-bit transmission systems. There are now solutions available that can provide an end-to-end chain for the delivery of live or on-demand programming to the viewer.

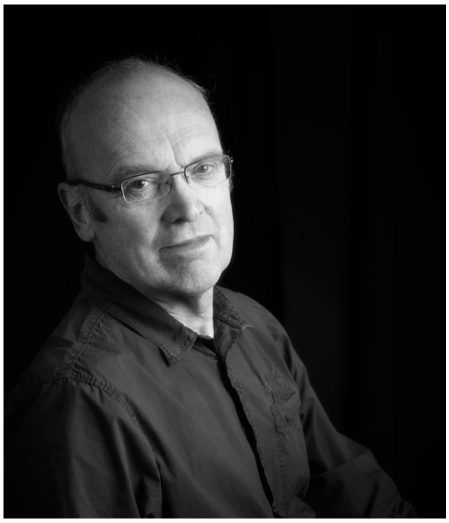
HDR production raises many issues. Can existing 10-bit SDI systems be used (yes)? What is the impact on the work of the shader? How is an SDR output derived alongside the HDR feed? What are the implication for metadata?

HDR is rapidly being adopted by OTT publishers like Netflix to deliver a premium product to their subscribers. Many of the cost and workflow issues around the simulcasting of live broadcasts in HDR and standard definition have also been solved.

The scales have been lifted from our eyes, as imaging systems can now deliver a more realistic dynamic range to the viewer.

This Essential Guide, supported by AJA Video Systems, looks at the challenges and the technical solutions to building an HDR production chain.

David Austerberry



David Austerberry

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High Dynamic Range Broadcasting

By David Austerberry, The Broadcast Bridge

As television has evolved, major changes in standards and technology have improved the quality of the viewing experience. After the momentous introduction of color, a range of evolutions have followed with the move from analog to digital, 4:3 to 16:9, and SD to HD. With each new step, broadcasters have had to overcome workflow challenges, and compatibility issues with legacy equipment. As modern broadcasters move from HD toward UltraHD and Standard Dynamic Range (SDR) to High Dynamic Range (HDR), the change is even more of a leap.

As with any new development, several approaches have emerged for HDR production, and are evolving. High Dynamic Range (HDR) television now exists in two primary formats, Perceptual Quantization (PQ) and Hybrid Log Gamma (HLG). Very different in concept, each offers unique advantages for different applications that this guide will cover in greater detail throughout.

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Generally, it could be said that HDR is a misnomer; what we had before was low dynamic range and now we have an imaging standard that better matches the human visual system (HVS). The original digital standards for television defined eight bits, 256 quantization levels, in a standard that was aligned to the performance of analog composite television. However, in the world of cinematography with either film and telecine or digital cinema cameras, it could easily exceed these constraints and deliver bit depths of 14 to 16 bits. This was used to advantage by the colorist in the creation of the final 8-bit transmission master.

Conventional Standard Dynamic Range (SDR) television exhibits many traits of its limited range including burnt out skies, blown out windows in interior scenes, and a lack of sparkle on specular reflections. Areas of high brightness clip to white. This is especially noticeable when saturated light sources appear in shot, typically in night scenes. The colored lights become desaturated, even white, and banding in the blacks is apparent. Shadows are further blocked with little or no detail.

A Director of Photography (DoP) may counteract these effects by filling shadow areas with light, covering windows with filters, and many other techniques to lower the overall dynamic range of the scene, while a sports director often doesn't have that luxury. The shady end of a stadium, for instance, cannot be sensibly lit to equal full sunlight at the other end. Sports like golf and sailing allow even less control over light.

These approaches are rapidly changing as HDR comes into the picture, enabled by advancements in camera and display technology, and accelerated by emerging standards in a race to improve pixels. Even with technological evolution, taking advantage of all that HDR has to offer requires broadcasters to carefully consider every aspect of their workflow from how they transform different HDR formats and shade, to how they account for SDR sources and metadata, when needed, throughout the live production chain.

Technological Advancements Driving HDR

Cameras

Modern digital camera technology now supports the capture of a much wider dynamic range, 15 stops or so, and at high bit depths up to 16-bit. This gives the colorist more artistic control over highlights and shadows in the creation of the final 10-bit or 8-bit transmission master.

Displays

In parallel, displays have improved, pioneered by companies like BrightSide Technologies, who first demonstrated that displays could have a higher dynamic range and was later acquired by Dolby Labs. Out of its research eventually came Dolby Vision. As CE vendors have encompassed technologies including quantum dots and modulated backlights to improve dynamic range, two main display technologies have surfaced for use in HDR monitors: the LCD and the OLED.

LCD is a light valve, with darkest black having limitations, whereas the emissive OLED display can achieve lower black levels limited only by reflections of ambient light. Current OLED displays cannot achieve the same peak white levels as the LCD, so the viewer has a fundamental choice when selecting a display and this is reflected in the HDR10 specification.

The Quest for Better Pixels and Its Influence on HDR Standards

Camera and display developments, coupled with higher resolutions (4K and 8K), fueled an industry-wide effort to improve pixels, and it quickly became clear that HDR was also an important factor, along with wide color gamut (WCG) to add to the realism of an imaging system.

Although consumer systems were 8-bit, most professional equipment used 10-bit SDI connections, so why not continue that bit-depth through the delivery chain to the consumer? The problem was the transfer function. Television is not linear and looking at the original display device, the cathode ray tube had a non-linear relationship between the electrical input and the light (optical) output that led to the use of a non-linear transfer function at the encoding (camera) stage. This was called gamma and was approximately the inverse of the CRT characteristic. From optical input to optical output the device was approximately linear, although modified to allow for the limited dynamic range that could be reproduced by the system and by artistic intent, raising or lowering the contrast of a scene.

By serendipity, the non-linear characteristic of the eye's response to brightness is roughly logarithmic. The eye follows a law defined by Weber and Fechner that implies a logarithmic relationship between physical stimuli and subjectively perceived sensation. In this case it's luminance and perceived brightness, which is comparable to the decibel, a logarithmic unit used to measure loudness in hearing.

With analog television, the use of the non-linear pre-correction fortuitously reduced the perceptual effects of noise in the transmission channel, but with digital, pre-correction makes more efficient use of the available bit-depth by making the perceptual quantization error among the video codes more uniform. If the quantizing step is too large it becomes visible as a posterizing effect. A linear coding scheme would need 11-bit coding to achieve the same visual performance as 8-bit coding with gamma correction.

However, the traditional 709 gamma (OETF) and BT.1886 (display EOTF) are unsatisfactory when stretched to a higher dynamic range. To get around the limits of 709 coding, camera manufacturers previously used proprietary log transfer functions to efficiently convey sensor data to post-production. These allowed a bit-depth reduction without perceptual loss.

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Looking forward, the demand for new standards in the quest for better pixels was clear, and out of this need arose Recommendation BT.2020, the UltraHD standard, and eventually BT.2100, which included HDR.

BT.2100 Examined

BT.2100 specifies a bit-depth of 10 or 12 for HDR television video productions. Most SDI infrastructure only supports a 10-bit signal path, although 12-bit coding can be supported in some dual-link schemes. In the immediate future, live HDR production is shaping up to be 10-bit.

BT.2100's development drew on the perceptual quantization (PQ) formalized in the SMPTE standard, ST 2084. The legacy Electro-Optical Transfer Function (EOTF) or gamma was based on the transfer characteristic of the cathode ray tube, and was finally specified in 2011, nearly a century after its inception, with the ITU recommendation BT.1886. Allied to that is Rec. 709 which details the Opto-Electronic Transfer Function (OETF) for the source, commonly referred to as gamma correction. This effectively pre-corrects for the non-linear transfer function of the CRT display, and this is emulated by later display technologies like the LCD.

12-bit coding is more likely to be found in motion picture production, where raw or 14/16-bit mezzanine log files from the camera can be delivered to post, for final delivery as 12-bit Dolby Vision or HDR10. The overall camera-to-display or Optical to Optical Transfer Function (OOTF) of an imaging system divides into the OETF and the EOTF. In practice this is modified by artistic intent.

Out of BT.2100 emerged two sets of HDR optical transfer functions, including PQ and Hybrid Log Gamma (HLG).

Breaking Down PQ and HLG

PQ achieves a wide range of brightness levels for a given bit depth using a non-linear transfer function that is finely tuned to match the human visual system (HVS). The goal is to reach a system with no visible banding or quantization effects. There are variants of PQ encoding, including 10-bit HDR10 with static metadata to signal to the display, and HDR10+, which adds dynamic metadata for improved control of tone mapping in the display as scenes unfold.

HDR10 is supported by Panasonic, Hisense and Samsung. Dolby Vision is a proprietary implementation, supporting 10 and 12-bit encoding with static and dynamic metadata. It is licensed to many CE vendors for displays and Blu-ray devices.

HLG, in contrast, is based partly on the transfer curve of the CRT and partly a log transfer characteristic. As HLG is not optimized for human vision, some of the coding space in the darker areas is wasted, and, with reduced peak white level, it cannot realize the potential dynamic range of PQ but aligns well with current available displays on the market for common nit levels.

HLG also tries to provide backwards compatibility for HD and the 4K SDR displays released before HDR standards were ratified. One of its major advantages however, is that no accompanying metadata is required to signal to the receiver beyond the basic format flag. Carrying metadata through a typical live broadcast or OTT distribution chain can be problematic, not to mention introduce issues around interstitials, ad breaks, bumpers, stings and other inserts of conventional broadcasting.

Another major differentiator between PQ and HLG, is that PQ is display-referred and HLG tends to be scene-referred, but what does that mean?

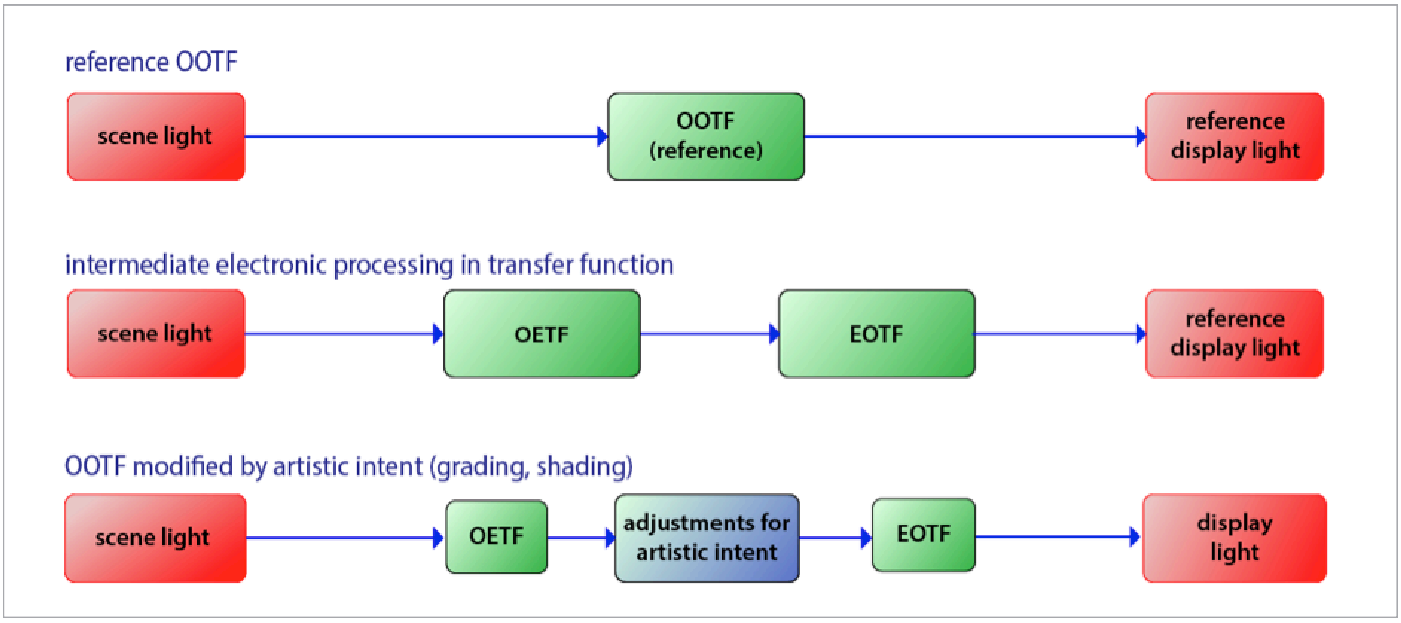

Figure 1 – Display referred and scene referred workflows.

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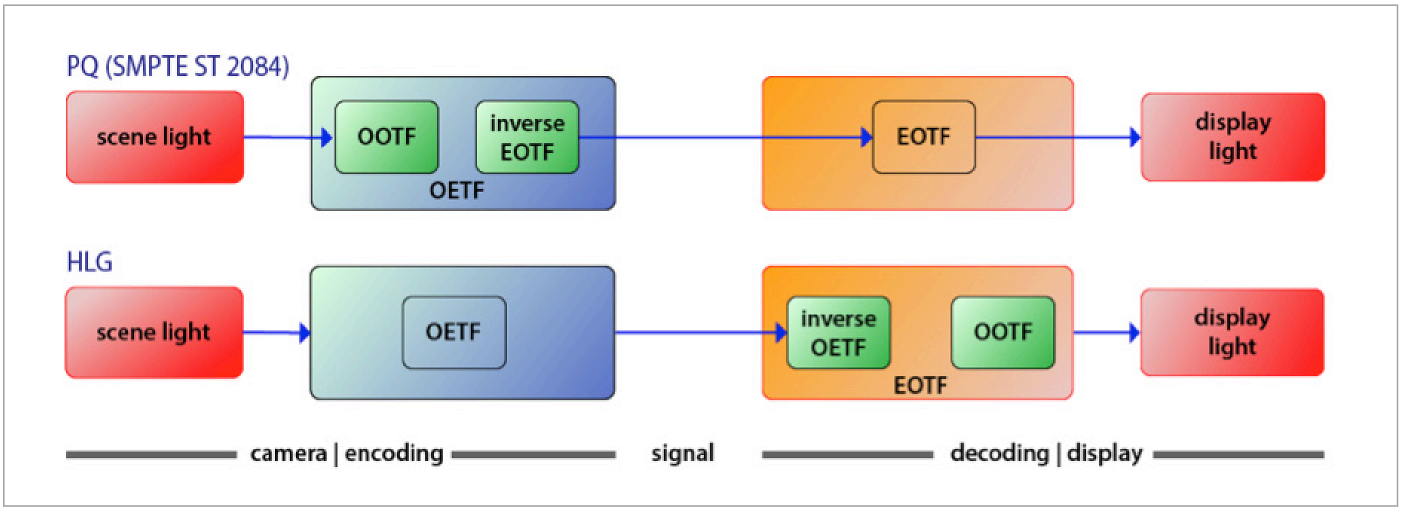

Figure 2 – PQ and HLG workflows.

Display- and Scene-referred

SDR television (709) references the electrical signal to the scene brightness, which is a scene-referred transfer function. PQ, on the other hand, references the electrical signal to the brightness at the display—display-referred. This stems from the fact that the PQ transfer curve references the brightness perceived by the viewer. It is optimized to match the contrast sensitivity of the HVS at differing levels of brightness.

HLG retains a scene-referred transfer function with its roots in the legacy 709 gamma. While it may not best optimize the system to the HVS, its advantage lies in the fact that the home viewer's display parameters can be different from the mastering display, and a satisfactory HDR picture can still be viewed. In the PQ world, if content were mastered on a display with a peak level of 2,000 nits and viewed on an OLED monitor with a peak level of 500 nits, then the content must be tone matched to the reduced capabilities of the home display. It's this simplicity that has made HLG popular for live video applications.

HDR however is not just about dynamic range, it's also about a wide color gamut (WCG) and in particular can lead to deeper and more realistic looking greens and golds, gold especially having been a challenge for broadcast for many years.

Color Space

One of the improvements of Recommendation BT.2020 is the larger color volume, stemming from a wider color space and an increased brightness range. 2020 defines a chromaticity that encompasses a much wider color space than 709 and DCI-P3.

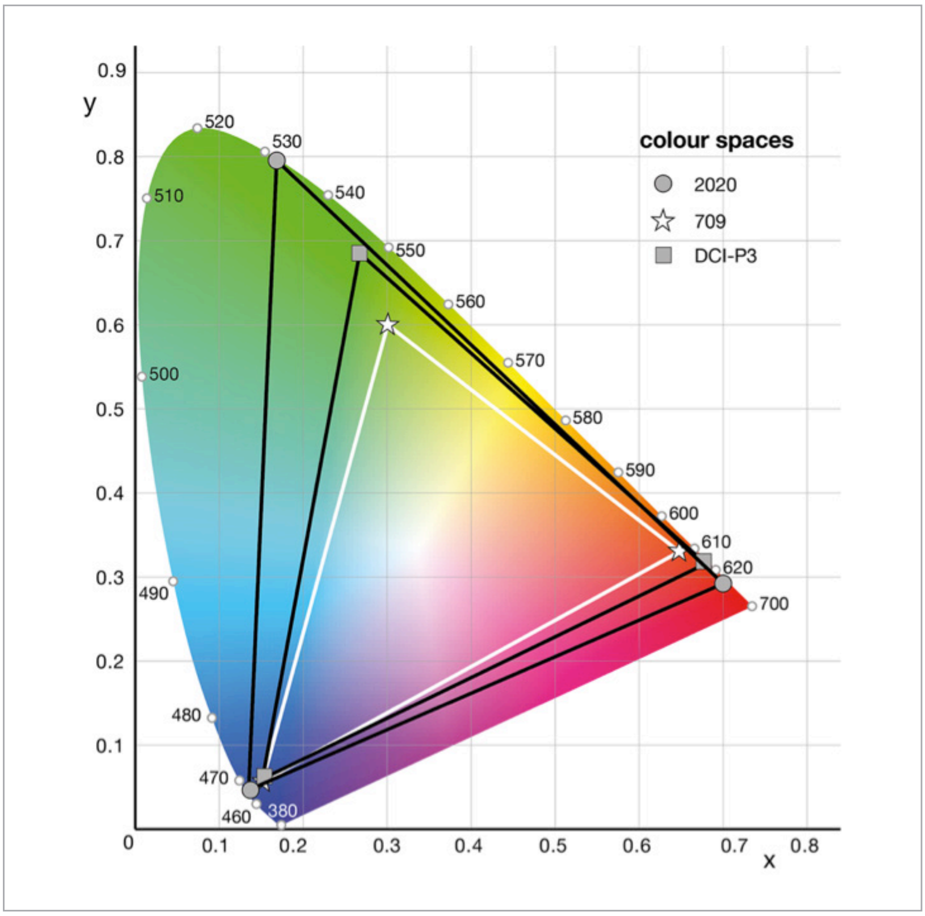

Figure 3 – BT.2020 wide color gamut color space compared to Rec.709 and DCI-P3.

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The sRGB standard used for computer displays and 709 and share a common space. The digital cinema projection standard DCI-P3 has a wider gamut, and includes more values in the red and yellow, important for skin tone reproduction. The much wider Rec 2020 color volume represents an aspiration, which cannot be achieved with current displays. This allows for future developments in display technology. Today P3 is the most realistic achievable target and has become the delivery requirement for many OTT outfits like Netflix and Amazon.

The usual diagrams of color space are two-dimensional, but it must be realized that color space is three-dimensional with a third, brightness axis. 2020 space is much taller than 709, representing the wider dynamic range. This larger volume accommodates up to 40% more saturated colors, 10 to 100 times brighter peaks and 100 times darker blacks than SDR 709 space. This volume allows for better reproduction not just of specular highlights but bright saturated colors like colored light sources and displays. Think of a fairground at night or a street scene with digital signage.

Standards talk aside, HDR and WCG introduce incredible new opportunities for broadcasters when done right, but there are several factors to consider in building an HDR workflow.

HDR Workflows Considerations

From a director's standpoint, finding a way to create SDR and HDR deliverables without the expense of two parallel production chains can be difficult, especially in live production. The producer is cognizant that the majority of viewers will be watching in HD SDR, while a small minority of early technology adopters will watch in UltraHD HDR. How does one achieve the impact of HDR without delivering a high contrast picture to regular viewers, with crushed shadows and blown out highlights? There is no single right answer, as a number of factors play into it and approaches vary. Following are a few key elements to keep in mind when trying to deliver a near perfect HDR picture for HD and UltraHD.

Format Transforms

Format transforms heavily influence the final look of HDR content. Most studios and trucks today use 8- or 10-bit signals. If a 10-bit coding path is used, then it is just on the edge of the visibility of quantization errors, but in practice this is masked by camera noise. 12-bit coding is optimum, but not practical for today's production equipment with 10-bit connections and processing.

In the 10-bit domain, it's recommended that concatenated conversions between HLG and PQ are avoided to minimize visible artifacts, so it's optimal to design a workflow that minimizes transforms. This indicates that a truck delivering HLG, should run HLG throughout, and similarly if the deliverable is PQ, PQ throughout. Should transforms be necessary it is important the converter uses a high-quality algorithm that minimizes artifacts.

A different approach is that taken by Sony with SR Live. This uses Sony's proprietary scene-referred log encoding, SLog3, as a capture format. It also is handled in the production switcher, then at the final output, the Sony log is transformed to HDR PQ or HLG and separately to SDR HD, but this method is not without shortcomings. It can be difficult to achieve the right look for both HDR and SDR at the same time; shading for one requires correction for the other.

The ultimate questions to ask in format conversions between 709 and 2020 include whether or not the gamut of colors should be expanded or if the colors should be clipped to the bounds or desaturated to fit. The HDR viewer will expect shots to match when intercut between the main HDR cameras and the converted SDR cameras.

To streamline these conversions and ensure a consistent quality picture, broadcasters and live production professionals have begun to embrace what is being called the single-master HDR workflow. Using HDR/WCG conversion technology, it enables conversion of HDR and SDR camera footage, graphics, inserts and replay content to a common HDR production format in real-time. This allows production to lean on HDR as the primary approach for mastering, while simultaneously providing a final HDR to SDR conversion for transmission to audiences viewing in SDR.

Shading

Artistic adjustments made with the camera shading controls also impact the final picture, whether on an SDR or HDR display. A higher bit depth is typically used internally before creating the final 10-bit output from the camera control unit, avoiding rounding and truncation errors of processing a 10-bit signal.

The challenge for directors managing a dual-format production is how to shade. The HDR image is likely going to need different settings from the regular SDR output if the advantages of HDR are to be enjoyed by the select viewers.

The amount of light reaching the sensor will be determined by aperture (iris), shutter speed, and whether ND filters are in the light path, so these controls are common. If an HDR and SDR program is being derived from an HDR camera there can only be one setting of the iris. If the aperture is set for a pleasing SDR picture, the HDR video will look too dark.

The gain, along with secondary paint controls, can be different for the HDR and SDR outputs. One solution that has been adopted by Sony is to have a fixed gain offset for the SDR output relative to the HDR. This is referred to as 'SDR gain'. The offset varies depending on the light. In bright sunlight is could be -10dB, in overcast low-contrast light it could be -6dB.

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The shaders control the cameras using SDR monitors and let the HDR output take care of itself. By this means the SDR and HDR image both look to have satisfactory contrast, but the HDR displays a wider dynamic range.

Grass Valley have added specific controls to their cameras that allow the shader to adjust the transfer function with gamma high, gamma low and gamma breakpoint. These provide the shader with the artistic control necessary to create a pleasing picture whatever the lighting conditions.

SDR Sources

For the near term, there is no escaping the use of SDR sources in live HDR production. Sports productions use all manner of specialist and slo mo cameras as well as regular PTZ devices for close-ups, suspended from cables, and underwater in pools, as well as Steadicam wireless rigs, most of which are HD SDR. Many established graphics devices and replay tools used across live production also don't support HDR. For instance, most graphics servers today output a key and fill channel including mostly SDR graphics. Furthermore, historical SDR content and SDR inserts are often existing within the same server, and needs to be integrated with live HDR content.

Upgrading to all HDR-capable equipment, is one solution, but just isn't a reality for all live production entities, especially considering the costs. Considering that a large majority of video content and graphics used in broadcasts or live productions is still SDR, there's a growing demand among professionals to be able to convert between SDR and HDR and even 709 and 2020. This is where the aforementioned single master HDR workflow can be a huge advantage. It helps to extend the life of existing equipment, while also preventing huge and costly infrastructure overhaul.

HDR: Marching Toward a Brighter Future

HDR represents the next big evolution in how we consume video, promising premium productions an edge in the constant competition for viewers. From live sports to studio shows, music and talent competitions, event coverage and beyond, every genre of television stands to gain tremendous benefits in the move to HDR, whether HD HDR or UltraHD HDR.

Production facilities do as well, as HDR capture can deliver a more dynamic picture, even when displayed in SDR, and it gives DPs the ability to create more compelling images in a wider range of challenging lighting conditions. CE vendors seeking an edge on their rivals have also started to pick it up.

Transitioning from SDR to HDR is relatively simple for production companies, with a host of technology now available to streamline the process. Existing camera sensor designs, for instance, already capture a wide dynamic range while switchers have been built to handle HDR signals. The addition of the latest camera base stations that can process and output HDR, along with converters to handle transforms in and out of the production switcher mean that HDR production is a small step for HD and UltraHD systems.

The successful deployment of HDR systems, however, requires a flexible system design that can accommodate legacy SDR sources, build on SDR workflows, and create separate or simultaneous HDR outputs in PQ and HLG as well as legacy SDR feeds. Solutions like AJA's FS-HDR real-time HDR/WCG converter and the single-master HDR workflow it supports provide a viable solution and will be key to cost control and the widespread adoption of HDR.

The coexistence of SDR and HDR equipment, both HD and UltraHD, are the reality of current productions. However, technological advancements are making it easier for production trucks and studio systems to interlink the differing formats, so that a final HDR production can be delivered in PQ or HLG, alongside an uncompromised SDR signal. This can be realized without the need for a parallel production chain, and without additional video engineering staff. With sensible compromises, the technical director and shaders can continue to operate as before. This bodes well for UltraHD HDR being a successful evolution from HD.

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The Sponsors Perspective

The Path Forward: A Single Master HDR Workflow

By Bryce Button, Director of Product Marketing, AJA Video Systems

From the Women's World Cup, Wimbledon to the FA Cup Final and more, 2019 has seen some of the highest viewership stats in sporting event history.

AJA FS-HDR Real Time HDR/WCG Conversion with the Colorfront Engine™ Video Processing.

This audience surge is attributable in part to the proliferation of OTT and consumer devices that provide more access to content, as well as the appeal of the perceived higher quality image facilitated by HDR production. With this continuing trend, embracing HDR will be crucial to live production professionals to remain competitive now, and futureproof their workflows for the years ahead, even if SDR remains the dominant deliverable. With HDR displays becoming more affordable and commonplace, HDR adoption in production is moving quickly, driving new momentum around an emerging live production approach dubbed the "single master" HDR workflow.

The concept is simple: streamline simultaneous live HDR and SDR production by leveraging a device like AJA's FS-HDR to convert HDR and SDR cameras and replay systems to a common HDR production format in real-time. When necessary, the workflow also supports seamless roundtripping of signals from SDR to HDR and back to SDR to accommodate graphics systems, package highlights and more, which may only be available in SDR as a source for integration into the HDR/SDR pipeline. This enables the production to be done with HDR as the primary approach for mastering and future proofing, while simultaneously providing a final HDR to SDR conversion for transmission to the larger viewing audience.

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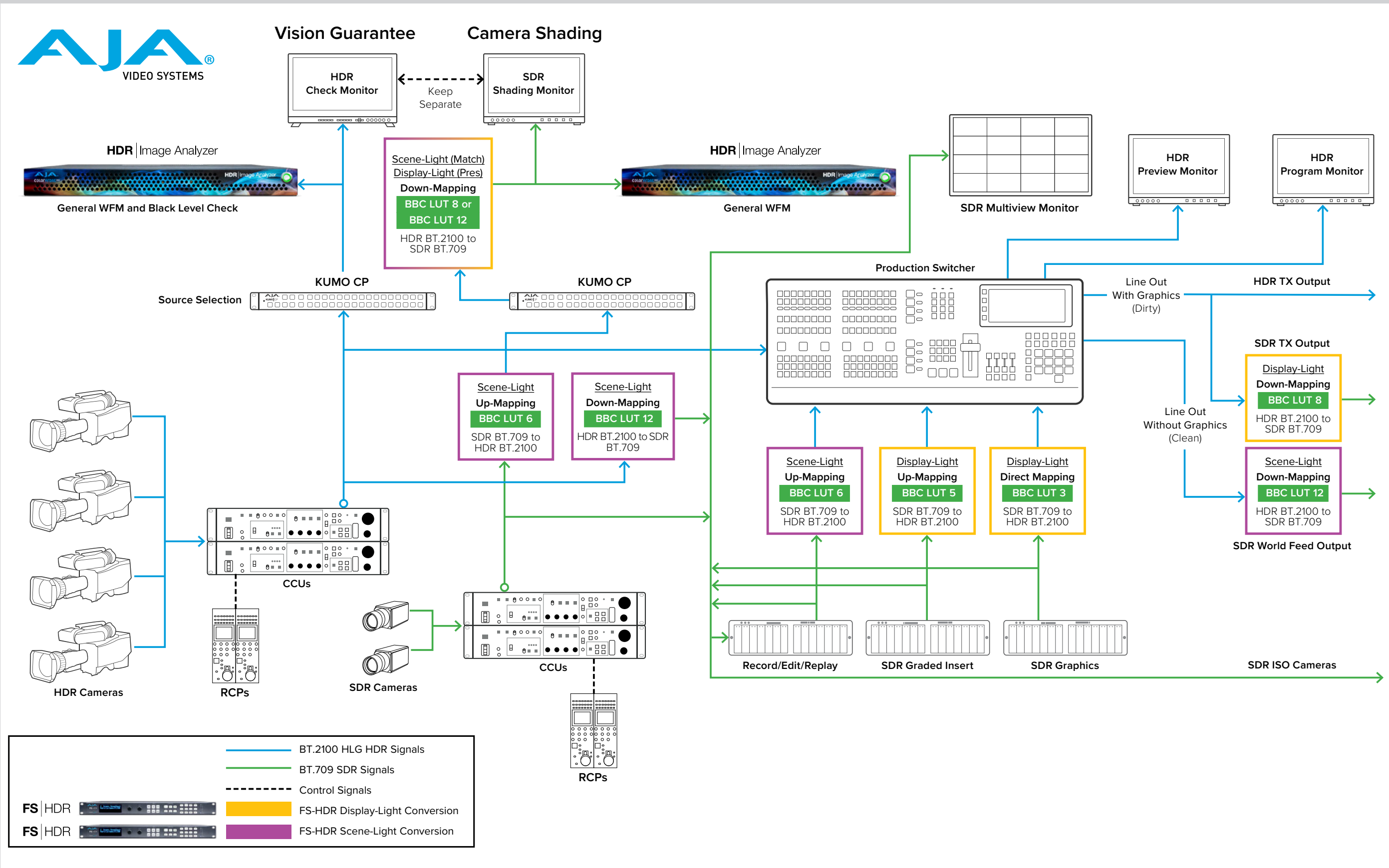
Prior to the introduction of the single master HDR workflow, developing an HDR pipeline that could support simultaneous live HDR and SDR production was no walk in the park. Companies often took a dual production approach and some still do. Such a workflow requires two production trucks or spaces, associated crews and a host of expensive equipment. The cost and complexity of this method makes it unattainable for live production professionals without sizable budgets. While camera manufacturers have worked to resolve this challenge with 4K UHD cameras that can simultaneously output SDR and HDR, these signals don't always match up, hence the need to be able to convert between Perceptual Quantizer (PQ), Hybrid Log Gamma (HLG) and Sony's S-Log 3.

The single-master HDR workflow makes HDR production more accessible to all live productions, because it only requires one switcher and one production format. Professionals can easily convert between HDR and SDR, and the images match up, so they get the quality picture needed for simultaneous streams of production with less gear, technology fuss and overhead. For these reasons, we're seeing a large number of professionals in live production adopt AJA's FS-HDR.

FS-HDR is a powerful converter in a 1RU chassis that supports conversions between SDR to HDR, HDR to HDR, and HDR to SDR for 4K/UltraHD and HD workflows. Some call it the Swiss Army knife of HDR production because it also supports frame synchronization as well as up, down and cross-conversion, with SDI transport that supports1.5G, 3G, 6G, 12G or dual link 3G, 6G or quad 1.5G, as well as 3G over copper and fiber.

Earlier this summer, outside broadcast powerhouse Arena Television put its single master HDR workflow to the test to deliver live simultaneous broadcasts in HDR and SDR for BBC Sport's coverage of the FA Cup Final, leaning heavily on the FS-HDR. BBC Sport chose to acquire footage in HDR for the FA Cup Final for OTT delivery, but also produced an HD SDR feed, as it knew a majority of the audience would watch the match in that format.

"FS-HDR was the key to unlocking the entire concept, giving us the highest possible quality HDR up- and down-mapping to bring audiences much more dynamic HDR and SDR pictures," shared Dafydd Rees, Deputy Director of Operations, Arena TV.



Single Master HDR/SDR Live Production workflow using BBC LUTs with FS-HDR and HDR Image Analyzer.

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AJA HDR Image Analyzer 12G.

Arena's workflow included a myriad of equipment, starting with Grass Valley cameras that output the main feeds in HLG or PQ HDR. 3G-SDI outputs were then fed into AJA FS-HDR for conversion to SDR for shading. For replays, slowed down replay materials were fed through FS-HDR for pass-on for simultaneous SDR and HDR output. Additional materials that required HD to 4K up conversion were then run through an AJA FS4 to ensure pristine 4K output.

Pre-recorded SDR materials were fed from an EVS device to an FS-HDR for SDR to HDR transformations. After the content was routed through other equipment, an AJA Hi5-4K-Plus enabled SDI to 4K HDR HDMI monitoring. Graphics for each broadcast started as 4K SDR sources that were sent through a combination of FS-HDRs and FS4s. The FS-HDRs supported 4K SDR to 4K HDR conversion and processing of the graphics fill, while an FS4 was used to control the key delay for final sync up of the two items that are then fed into an EVS server.

"We picked FS-HDR because we know AJA FS gear is reliable, plus FS-HDR's dual power supplies also give us redundancy," noted Rees. "Overall, we found FS-HDR to be a powerful device that does all that it claims to do; it gives you all the tools you need to get the job done, from an intuitive interface to powerful processing, and that's a dream in this industry."

Arena will continue to refine its single master HDR workflow with each new production it takes on and collaborate with AJA's development team as it does. "In this business you learn something new from every project, and failure to do so means you're not doing your job. The FA Cup Final was a huge, complex undertaking from which we gained valuable takeaways that we can apply to future HDR productions," added Rees. "FS-HDR is extremely valuable kit, our swiss army knife for HDR production."

Arena is one of many live production companies making the move to a single master HDR workflow and we expect many to follow in the coming months, especially as consumer demand for live HDR content grows. As more do, AJA will continue its efforts to work with customers to improve its technology and extend what's possible in the field. For more information about FS-HDR and other AJA HDR solutions, please visit: www.aja.com/solutions/hdr.

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