REAL-WORLD LIVE 4K ULTRA HD BROADCASTING WITH HIGH DYNAMIC RANGE

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ABSTRACT

Interest in High Dynamic Range (HDR) for live broadcasting continues to increase. Well publicised trials completed within the past year have proven that Ultra High Definition (UHD) images with HDR can be captured, delivered and displayed to viewers on HDR-capable TV screens (1)(2). A number of broadcast organisations are now moving to the next phase of development, drawing up plans to implement permanent on-air UHD services including HDR. In most cases, the new services will be delivered alongside existing High Definition programming and in many cases a simultaneous Standard Dynamic Range (SDR) feed at 3840 x 2160 resolution will be required. This paper will examine the technical and operational challenges presented. An example of a production infrastructure designed from first principles to overcome these challenges is provided.

INTRODUCTION

The first public demonstrations of the live production and delivery to home of 3840 x 2160 images were held in the early 2010s. These early trials prioritised the broadcast of higher resolution images over increased dynamic range or wider colour gamut. They were the result of advances in technology throughout the content production, delivery and display chain, alongside a close collaboration between the broadcasters, outside broadcast service providers, telecommunications providers and equipment vendors involved. The trials paved the way for the first 4K UHD services on air today.

Recent advances in areas such as image capture, OETF/EOTF conversion, colour space management and home display technology, along with developments in industry standardisation have created the possibility of live UHD broadcast services with the addition of HDR and Wide Colour Gamut (WCG).

Against this background, this paper examines a real-world technical infrastructure designed specifically for a 4K UHD service with High Dynamic Range. The system under review has been designed for the regular broadcast of live sports events where UHD services with HDR are delivered alongside UHD Standard Dynamic Range and HD services. The paper describes the physical infrastructure employed and highlights the various UHD, HDR, SDR and HD sources included within the system. The use of the S-Log3 transfer function as the production OETF is examined. The location of the various colour space and OETF/EOTF conversions are also shown.

The production infrastructure under study is based upon a number of practical systems that have been implemented around the world. These include the system at Canadian Communication and Media Company, Rogers Cable for forthcoming 4K UHD live services.

In additional to the description of the technical infrastructure, the paper also examines the operational considerations to be addressed. The operational set up and live adjustment of picture parameters have been key factors evaluated within live broadcast trial to date. The paper provides recommendations for adjustment and monitoring of images within the programme chain to provide maximum quality for the various deliverables. The controls available to the operators are explained. The results obtained continue to drive product development and the paper examiners the state of play in today's systems.

TECHNICAL AND OPERATIONAL CONSIDERATIONS

The scope of technical trials to date has been determined by the availability of the various components within the end-to-end programme chain. Initial trials on UHD with HDR primarily investigated the performance of "UHD only" HDR production infrastructures with UHD cameras used for capture. This was largely the result of the earlier availability of camera chains, recording devices and consumer TVs incorporating either production or prototype firmware for UHD operation. Investigation of the appropriate HDR transfer functions for production and delivery was also a key requirement.

The move to a permanent service however, introduces new challenges. These include the need to mix HD and UHD source material within the programme, the inclusion of graphics and the requirement for conversion of colour space and resolution within the chain. Adjustments to operational practice may also be required to optimise the quality of the various HD, UHD, SDR and HDR deliverables under varying conditions of location and time of day. At the same time, the operational focus is on providing the multiple deliverables with minimal impact to current practices and limited additional requirement in terms of staffing. Any requirement for new vision engineering and camera operating practices will need to be minimised.

TECHNICAL INFRASTRUCTURE

An example of a practical production infrastructure addressing the various technical and operation challenges is shown in Figure 1.

At the heart of the system is a latest generation 4K UHD multi-format video switcher. The switcher is configured to operate in 3840 x 2160 resolution with 4 x 3G-SDI interfacing for UHD. It accepts sources that are 3840 x 2160 native or have been up converted from sources with an original resolution of 1920 x 1080. Sources to the switcher are presented using the S-Log3 gamma OEFT (3) via an OETF conversion where necessary. A colour conversion to BT.2020 colour space is also performed for sources originated in Rec. 709.

The Choice Of S-Log3

S-Log3 (3) is the latest in a series of gamma functions originally developed by Sony for use in electronic cameras for cinematography - Figure 2. The original S-Log characteristic (4) allowed digitally originated high dynamic range images to be processed within a 10 or 12 bit post-production environment using similar techniques as those employed for images acquired using film. S-Log3 is based on Cineon Digital Negative and has a wider dynamic range than the earlier S-Log and S-Log2 (4) characteristics.

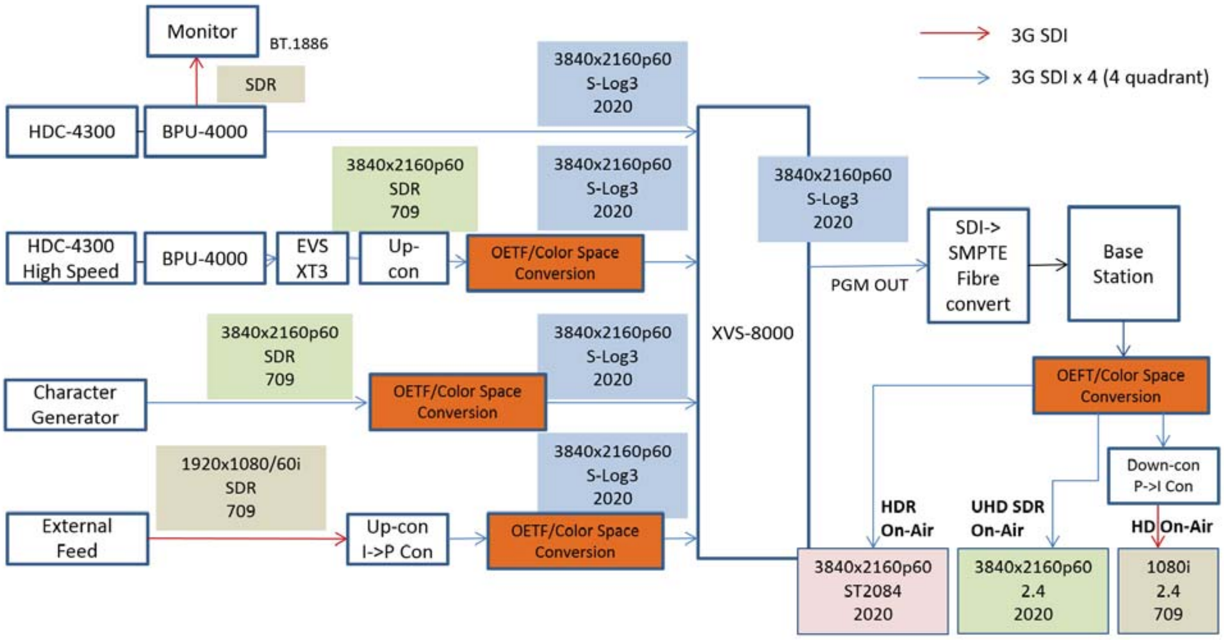

Figure 1 – Production system for live broadcast of UHD images with HDR

S-Log3 has been optimised for use with latest generation CMOS sensors found in single sensor cameras for cinematography and is equally suited to three ⅔-inch sensor cameras used for live studio and outside broadcast applications.

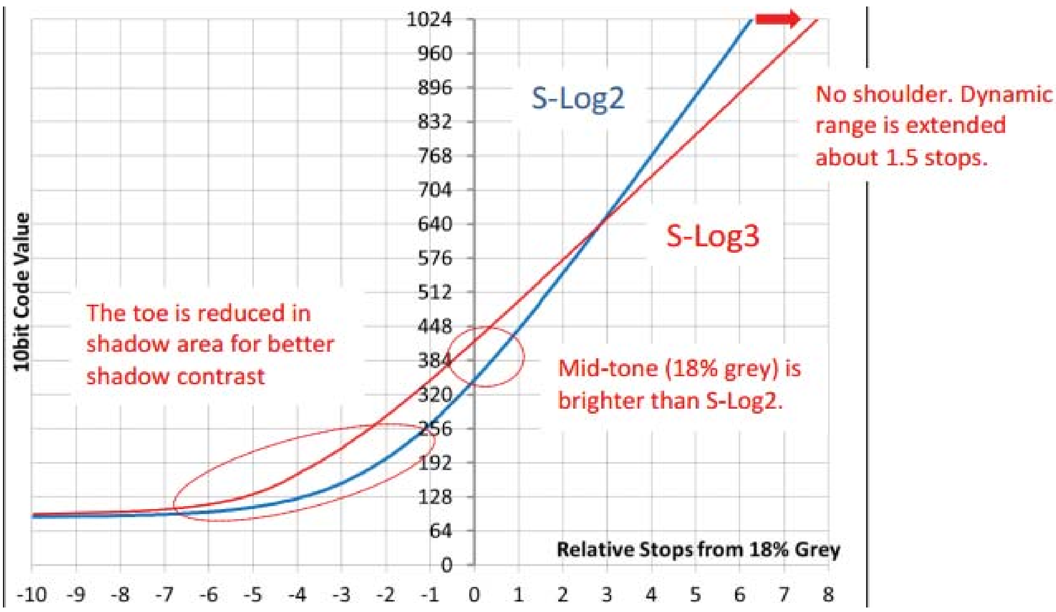

Figure 2 - The S-Log2 and S-Log3 tone curves.

S-Log3 was selected to facilitate an efficient and high quality 10 bit operation. Natural image reproduction is achieved through a well-balanced bit allocation across the full range of input luminance. Particular care around skin tones has also been taken and maintenance of high picture quality when converting to the distribution and display EOTF was also a factor in its choice.

Camera Feeds

Sony HDC-4300 system cameras provide the majority of UHD images within the system. Each camera head contains three ⅔-inch CMOS sensors each with 4096 x 2160 resolution. The cameras are paired with BPU-4000 Baseband Processor Units configured to provide 3840 x 2160 outputs via 4 x 3G-SDI feeds. The camera systems are set to S-Log3 with BT.2020 colour space for WCG. The output from each BPU-4000 is fed directly to the production switcher. The design of the BPU provides a degree of flexibility for infrastructure design and operational control within HDR-specific or mixed HDR/SDR environments - Figure 3.

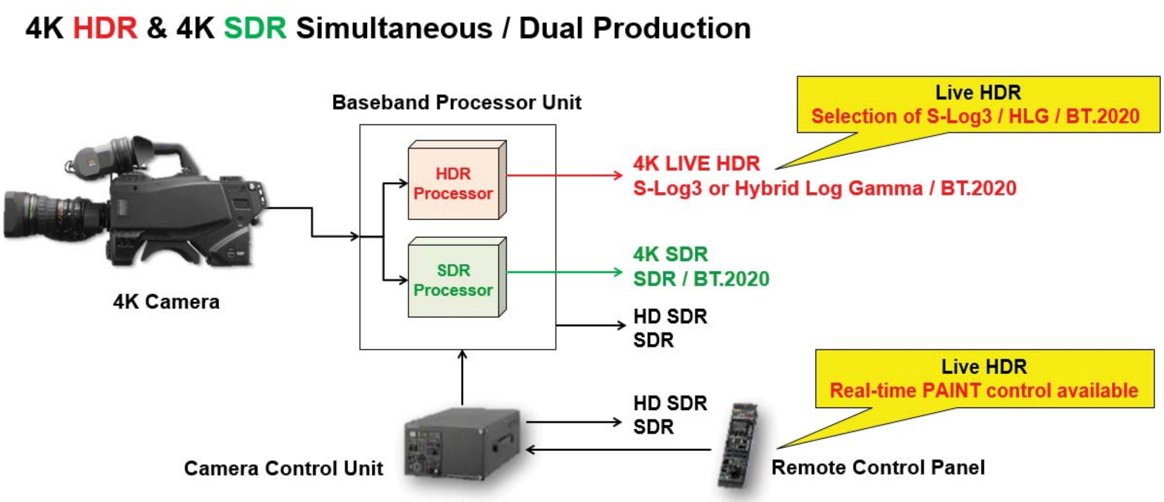

Figure 3 - Ultra HD camera chain with individual processing for HDR and SDR.

Individual signal paths for HDR and SDR at 3840 x 2160 resolution are provided within each BPU device. Signal parameters for each path can be individually adjusted. This configuration allows the system designer the choice of implementing separate HDR / SDR signal flows within a system with separate control of each. An alternative method of using a single UHD HDR signal flow with either HDR or SDR monitoring is also possible. In the system under study, the system was designed to produce a single UHD HDR Programme Output from the switcher and to derive the required UHD HDR, UHD SDR and HD deliverables from this Programme Output.

External Feeds

External sources arriving in 1920 x 1080 resolution are first converted to 3840 x 2160 resolution using AJA FS3 4K Upconverters. The output of each upconverter is then processed for colour space and gamma conversion prior to arrival at the switcher. An upconverter, photographed during pre-testing of the system is shown in Figure 4.

Figure 4 - The Upconverters, as used within the system.

Colour Space And Gamma Conversion

The conversion of colour space and gamma transfer function throughout the system is performed by a series of FujiFilm “IS-mini” devices. Four converters are used for each 3840 x 2160 source, one for each of the four Quad Link 3G-SDI connections - Figure 5. Look Up Tables (LUTs) loaded into each device, control the parameters of the conversion.

Figure 5 - Colour space and gamma converter (lower unit).

Slow Motion Capture And Replay

Multiple SDR inputs are managed within the system. An example is slow motion content captured by the 4K cameras set to record in HD resolution with SDR. Upconversion to 3840 x 2160 is performed immediately prior to switching, with conversion to S-Log3 again handled using the Im converter shown in Figure 5.

Storage

Although not specifically shown in figure1, multiple PWS-4400/4500 4K/HD multi-port AV storage units were used to record and replay content. The XAVC format (5), complying with H.264 level 5.2, was used to encode the video essence before recording onto the storage unit.

Graphics

Another example of an SDR-originated source is the output provided by the graphics system. Conversion to BT.2020 and S-Log3 is completed before input to the switcher.

Monitoring

Monitoring of the individual EOTFs selected by the content producer is critical to satisfy the artistic and operational requirements of the production. The HDR displays used must ensure a high level of precision of HDR image reproduction with adequate peak luminance, contrast and by-pixel emission. Flexibility to accommodate the range of industry standard EOTF/OETFs and the camera specific OETF is required. Monitors which support the ST 2084 perceptual quantisation curve, Hybrid Log Gamma and S-Log3 will meet the critical requirements of the system under investigation. These include the BVM-X300 and PVM-X550 OLED models.

The section “Operational Considerations” later in the paper examines alternative monitoring arrangements for systems where the cost of using multiple 4K UHD master reference monitors may be prohibitive.

Programme Output

The Programme Output from the switcher is output via 4 x 3G-SDI in 3840 x 2160 resolution with S-Log3 and BT.2020. This is converted to the resolution, colour space and EOTF required for distribution and delivery of the various feeds. Multiple FujiFilm “IS-mini” devices are again used to perform the colour space and EOTF conversions with the appropriate LUTs on board for control of the parameters of each conversion. In the system under study, the SMPTE ST.2084 EOTF has been selected for delivery and display of the on-air UHD HDR programme with delivery to the home via IP. Down conversion to 1920 x 1080 is performed for the HD feed after colour space and EOTF processing. The UHD SDR feed is generated by the conversion of the programme output to 2.2 gamma.

Delivery to Home

Multiple delivery mechanisms have been proposed for delivery of HDR content to the home. Individual discussions are on-going for each proposal within the Standard Development Organisations and industry forums, with support by proponent parties including broadcasters, technology service vendors and manufacturers. Options include the following:

HDR10

HDR10 employs HEVC Main 10 profile and the ST 2084 EOTF (6) with static metadata. It is specified by the Consumer Technology Association (CTA) for implementation within HDR-capable TV sets and is mandated for Ultra HD Blu-ray.

Key characteristics are as follows:

- HEVC Main 10 profile Level 5.1 single layer
- Transfer curve: SMPTE ST 2084 (PQ)
- Colour gamut: Rec. ITU-R BT.2020
- Bit depth: 10 bits
- Metadata included: ST 2086, MaxFALL, MaxCLL

Single and Dual Layer HDR Technologies

Dolby and Technicolor/Philips respectively propose specific technologies for HDR delivery.

Dolby is a proponent of Dolby Vision, using the ST 2084 OETF. Its dual layer structure is composed of a base content layer with static metadata and an enhanced content layer with dynamic metadata.

Technicolor/Philips propose a single content layer with metadata which reproduces the HDR signal. The solution also claims SDR TV set backward compatibility.

Hybrid Log Gamma

The BBC and NHK propose Hybrid Log Gamma (7). This is defined as a camera capture transfer curve, or OETF. This curve was designed to provide HDR while maintaining a degree of compatibility with legacy SDR displays. The HLG curve has been specified in ITU-R HDR-TV Recommendation BT.2100.

OPERATIONAL CONSIDERATIONS

The operational aspects of starting a UHD service with HDR have been key areas of study within the live broadcast trials completed to date. The configuration and live operation of the individual camera chains has been one area that has been actively investigated. For reasons of operational efficiency, the system under study was designed around a single UHD HDR production core, thus removing the requirement to process both HDR and SDR feeds throughout the production chain.

A technical infrastructure configured in this way requires careful set up of each camera chain. This is necessary to ensure that the exposure and colour parameters of each camera are set up to provide the best quality for each deliverable derived from the switcher Programme Output. The question of whether to monitor the camera outputs in HDR or SDR is also an important factor.

Within the camera chains used, the Baseband Processor Units have been designed to offer flexibility so that the user can integrate the camera chain into a chosen workflow. The ability to simultaneously monitor in UHD with HDR, UHD with SDR and HD with SDR is provided along with dedicated parameter adjustments for each signal path.

As an example, for a single simultaneous HDR/SDR workflow, the operator can choose to perform an initial camera set up to correctly expose the image for HDR. As the camera iris will naturally be more open than when shooting in SDR (+1 stop to +2 stop in experimental trials), a consequence is that the derived SDR images will be over-exposed in critical areas of the picture. Monitoring of the SDR output from the camera and applying negative gain to the HDR signal will help overcome this problem. Any subsequent misalignment of HDR and SDR black level can be corrected by adjusting the individual

HDR and SDR black level controls within the camera processor. The operators can then choose to "Rack" the production in SDR and to provide an SDR feed to the viewfinder for the camera operator. The selected SDR gain and black level parameters can then be applied within the post-switcher conversion process to provide the correctly exposed and adjusted images for the UHD SDR and HD SDR feeds.

CONCLUSIONS

The technical and operational challenges of setting up a broadcast system for a live UHD service with HDR have been described. The paper has examined a production infrastructure designed around the use of S-Log3 and BT.2020 with multi-format inputs and UHD HDR, UHD SDR and HD deliverables. Various operation challenges around image quality and control have been addressed. As the majority of components within the system are commercially available today, a real world system can now be practically realised by end users who wish to create more engaging UHD content for their viewers.

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