Introduction

High Dynamic Range (HDR) video formats can represent brighter highlights and increased shadow detail, making scenes more natural, adding realism, and enlarging the creative palette for grading and shading. Wide Color Gamut (WCG) and HDR increase the potential range of colors available.

As broadcasters migrate to HDR and WCG, viewers of SDR content mustn't be adversely affected. Therefore, broadcasters undertaking HDR production need to produce both SDR and HDR versions of their content for the foreseeable future. Here, we provide a brief overview of a production workflow to efficiently create and deliver "live" HDR and SDR content.

Two approaches to HDR television are specified in ITU-R BT.2100[1]: the display-referred Perceptual Quantization (PQ) and scene-referred Hybrid Log-Gamma (HLG). A PQ signal describes the absolute light that the display should produce, while an HLG signal represents the relative light in the scene, whether real or virtual. The difference between PQ and HLG significantly affects production, transmission, and delivery workflow.

Traditionally, in non-live workflows, assets are created independently for HDR and SDR when time allows from a single capture format that supports the maximum dynamic range. This format is typically a "raw" or "log camera" format where either a scene-referred or display-referred approach can be used for offline grading. Two grades for SDR and HDR provide maximum control over the look in both formats. Alternatively, given budget or time constraints, a color transform can be used to derive a converted, high-quality SDR asset from an HDR master, albeit with slight artistic compromises.

Live Single-Master HDR-SDR Production Workflow

In live productions, it is neither cost-effective nor practicable to duplicate equipment, workflows, and crew for separate SDR and HDR productions. Large-scale live productions commonly use multiple cameras from different manufacturers, including specialist cameras that may not be capable of native HDR. Productions will have archival content, live inserts, and graphics in legacy formats that must be converted to a shared production format. At the time of writing, most live HDR television productions use an HLG scene-referred approach, and some use Sony's proprietary S-Log3 format. The HLG production format is distribution-ready or can be converted to PQ (HDR10, Dolby Vision or HDR10+). The single-master workflow has been developed to provide SDR and HDR deliverables derived from one master HDR production format. It is more fully described in Report ITU-R BT.2408-7[2].

The single-master workflow is built around a central HDR production switcher. All inputs to the production switcher are either native HDR or converted to HDR by an appropriate SDR-to-HDR (up-mapping) color transform. Inputs to SDR monitors are derived from HDR sources. The switcher output is HDR and provides the HDR program feed, while an HDR-to-SDR (down-mapping) color transform of that program provides the SDR feed for transmission. The same down-mapping process is used to drive SDR shading monitors. The up-mapper is matched to the down-mapper, so a roundtrip (SDR – HDR – SDR) is possible.

Understanding which specific transforms to use is critical to Single-Master Production Workflows, and care must be taken to choose the correct type at each position in the workflow. Display-light transforms maintain the look of an image and are used for most conversions. However, scene-light transforms will best match colors in the original live scene and are therefore used so that any non-HDR camera feeds will match the native HDR cameras. Two

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[1] Recommendation ITU-R BT.2100-2 "**Image parameter values for high dynamic range television for use in production and international programme exchange,**" https://www.itu.int/rec/R-REC-BT.2100
[2] Report ITU-R BT.2408-7 "Guidance for operational practices in HDR television production," https://www.itu.int/pub/R-REP-BT.2408 (see Section 5, 7, Annex 9 and 10)

approaches to static HDR-to-SDR down-mapping have evolved: one using a non-linear, "gamma-adapted" conversion and one using a linear conversion (see ITU-R BT.2408-7, section 5.2).

At present, and for most productions, SDR shading remains the focus since it represents the format most customers view.   The shading station may either have an SDR monitor, with an HDR check monitor positioned separately or include both SDR and HDR monitors nearby. Where the HDR and SDR monitors are nearby for shading, the displays' reference white luminance levels must be matched to avoid eye adaptation issues due to brightness differences between the two displays (see ITU-R BT.2408-7 Annex 9).

Single-Master Production Workflow
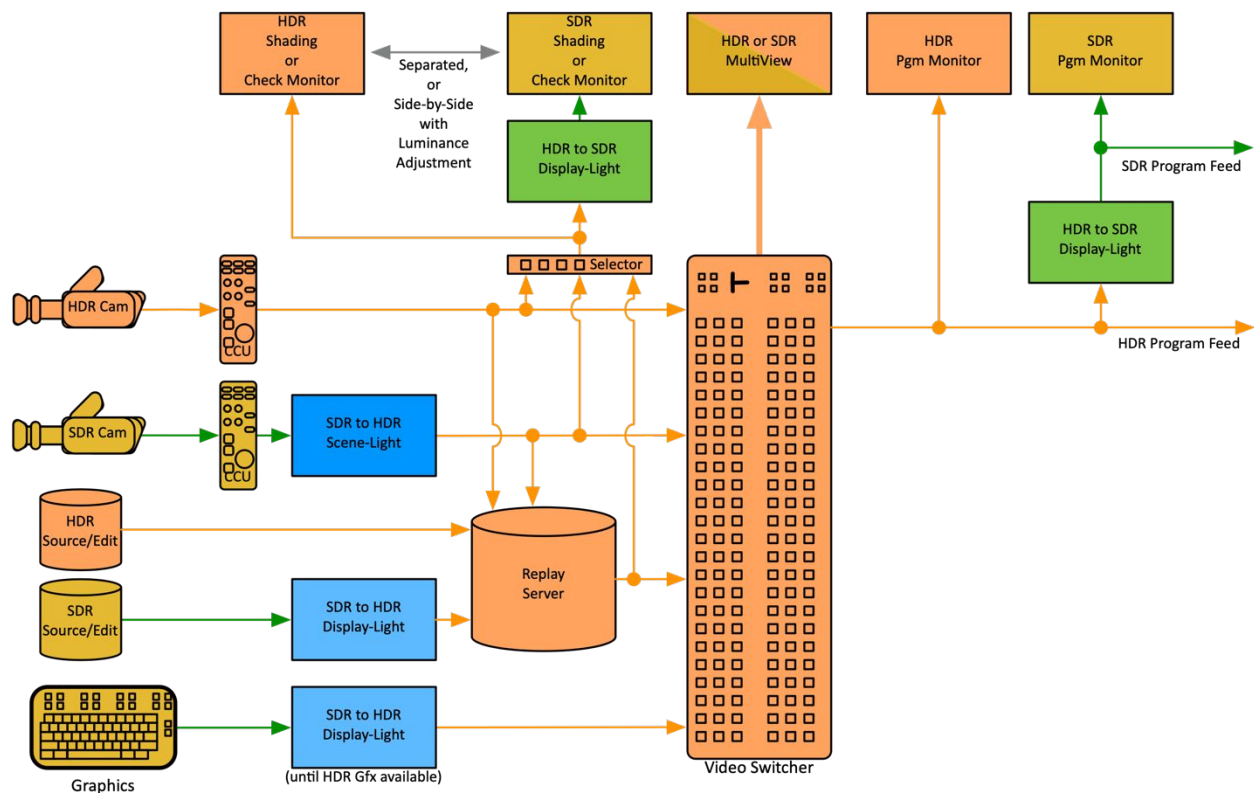
Examples of Successful Deployments:

BBC
- Soccer: FA Cup 2019[3], Euros 2020[4], FIFA World Cup 2022
- Tennis: Wimbledon 2023
- Music festivals: Glastonbury 2022, Glastonbury 2023
- Public interest events: Queen Elizabeth II's Platinum Jubilee 2022, Coronation of King Charles III and Queen Camilla 2023[5]

NBCUniversal Live Sports[6]
- Soccer
- Olympics (Beijing and Tokyo)[7]
- Football
- Basketball
- Baseball
- Golf [9]

TNT Sport (Previously BT)
- Soccer
- Boxing, Rugby
- Motocross

Host Broadcasters
       OBS – Olympics, HBS – World Cup, UEFA - Soccer

Sky Sports and Entertainment
- Soccer
- Cricket
- Formula 1
- Boxing
- Golf
- Darts
- Rugby
- Rolling news channel: Sky Sports News
- Music Festivals: IOW
- Public interest events (In conjunction with BBC)

Fox Live Sports
- Football
- Baseball

Amazon Live Streaming Sports
- College Football

CBS Live Sports
- Golf [9]
- Football (Superbowl 2024[8])
- Basketball

Guidelines Information

HDR features throughout the Guidelines Rainbow books as a foundational Ultra HD technology. The respective sections for Single-Master Production Workflows are listed below:

Green Book-Ultra HD Distribution, Section 9.5 on a Typical Live Streaming Workflow

Blue Book- UltraHD Production and Post Production, Section 7.1 on HDR and WCG Technologies, Section 8 on Conversions between Transfer Functions, Section 9.2 on Conversions from SDR/BT.709 to PQ10 and HLG10, Section 9.3 on Conversion from PQ10/HLG10 to SDR BT.709, Section 11 on Production for Live Content

Indigo Book-Ultra HD Technology Implementations, Section 10.3 on NBCU Single-Master HDR-SDR Workflow Recommendations

Violet Book- Real World Ultra HD, Section 13 on Real World Foundation Ultra HD Deployments

NB: Copies of the Guideline Books can be found at: https://ultrahdforum.org/guidelines/

[3] https://www.bbc.co.uk/rd/blog/2019-08-uhd-hdr-fa-cup-football-live-sport-production
[4] https://www.bbc.co.uk/rd/blog/2021-07-uhd-hdr-television-production-workflow
[5] https://www.bbc.co.uk/rd/blog/2023-05-coronation-uhd-hdr, https://www.bbc.co.uk/rd/blog/2023-12-uhd-hdr-production-architecture-coronation
[6] NBCU Single-Master UHD-HDR-SDR Production-Distribution and LUTs
[7] NBCUniversal Tokyo Olympics - Reflects on a Unique Games Experience
[8] https://www.sportsvideo.org/2024/02/06/super-bowl-lviii-paramount-takes-a-major-step-toward-100-hdr-workflow
[9] https://www.sportsvideo.org/2024/01/25/pga-tour-enters-new-era-of-1080p-hdr-production-with-new-trucks/