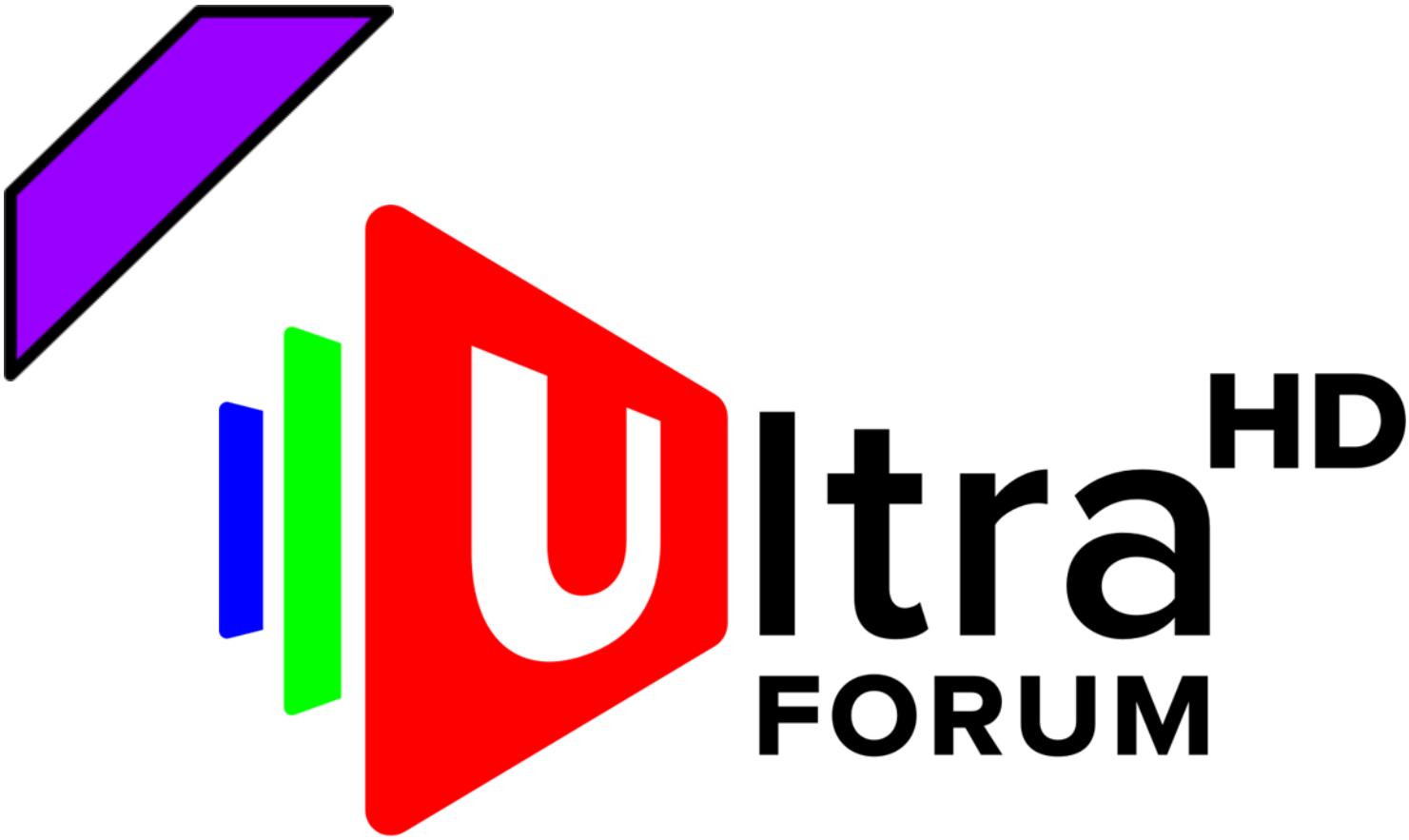

Ultra HD Forum Guidelines

Violet Book – Real World Ultra HD

Ultra HD Forum

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UNITED STATES

VERSION 3.3.0

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1. Foreword

The Ultra HD Forum Guidelines provides a holistic view of modern media systems, their mechanisms and workflows, and how those are impacted by the latest generation of improvements – the “Ultra HD” technologies, those that take media beyond the limits established at the start of this millennia, as characterized in large part by the video resolutions and the dynamic of “high definition” (i.e., ITU-R Rec. BT.709). The Forum considers Ultra HD to not only be any UHD media (i.e., 4K resolution, or higher), but also HD-resolution media with enhancements such as High Dynamic Range, Wide Color Gamut, etc. Ultra HD is a constellation of technologies that can provide significant improvements in media quality and audience experience. In addition, the Forum collaborates in promoting the understanding of the various deployments and delivery methods for Ultra HD media that continuously evolve around the world.

This work represents over eight years of collaborative effort by the membership of the Ultra HD Forum. The Ultra HD Forum’s Guideline books would not have been possible without the leadership of Jim DeFilippis, who represents Fraunhofer, and chair of our Guidelines Work Group with invaluable support from the co-chair, Pete Sellar of Xperi as well as technical assistance from Ian Nock of Fairmile West Consulting, chair of the Interop Working Group.

Our gratitude to all the companies listed in the Acknowledgments that have participated in this effort over the years and specifically to Nabajeet Barman (Brightcove), Elena Burdiel Pérez (Fraunhofer), Andrew Cotton (BBC), Jean Louis Diascorn (Harmonic), Richard Doherty (Dolby), Felix Nemirovsky (Dolby),Chris Johns (Sky UK), Katy Noland (BBC), Bill Redmann (InterDigital), Yuriy Reznik (Brightcove), Chris Seeger (Comcast/NBCUniversal), Adrian Murtaza (Fraunhofer) and Alessandro Travaglini (Fraunhofer).

This document, *Real World Ultra HD* (Violet Book), is one of a series of books, referred to as the Rainbow Books, that compose the Ultra HD Forum Guidelines. If any of these terms sound unfamiliar, follow the link below to the Black Book. If a particular standard is of interest, links

such as the one above are available to take you to the White Book, where references are collected.

The Rainbow Books are, in their entirety:

White Book	Guidelines Index and References
Red Book	Introduction to Ultra HD
Orange Book	Foundational Technologies for Ultra HD
Yellow Book	Beyond Foundational Technologies
Green Book	Ultra HD Distribution
Blue Book	Ultra HD Production and Post Production
Indigo Book	Ultra HD Technology Implementations
Violet Book	**Real World Ultra HD**
Black Book	Terms and Acronyms

Updates in this new version of the Ultra HD Forum Guidelines are described on the following page.

I hope you will enjoy reading today.

If you want to know more about Ultra HD, and join our discussions on how it can be deployed, I invite you to join the Ultra HD Forum. You can start by visiting our website: www.ultrahdforum.org.

Dr. Yasser Syed, President, Ultra HD Forum
Sept 2024

1.1. Changes from version 3.2 to 3.3

What's new in the Spring 2024 version of the UHDF Guidelines Violet Book, *Real World Ultra HD* (v3.3), edited by Ian Nock.

The *Real World Ultra HD* is the seventh of the series of Rainbow Books on the Guidelines for Ultra HD. The scope and purpose of this book is to inform the reader regarding the variety of Ultra HD devices and best practices for distribution of Ultra HD content to them. Specific information on devices that support Ultra HD Foundational technologies as well as device considerations for advanced Ultra HD technologies such as Dolby Vision, HDR 10+, AC-4, MPEG-H, DTS UHD. Real world examples and case studies of Ultra HD distribution are described.

While most of the information in this edition is material from the previous version of the Guidelines (v3.2), the information around Edge Devices has been updated with more pertinent details with regard to capabilities of the devices and issues with regard to Display policies.

We hope this new format will be helpful in understanding Ultra HD technologies as well as planning for new or expanded Ultra HD services.

Jim DeFilippis and Pete Sellar,

Guidelines Working Group Co-Chairs, Ultra HD Forum, Spring 2024

2. Acknowledgements

We would like to provide the acknowledgement to all the member companies, past and present, of the Ultra HD Forum who have contributed in some small or large part to the body of knowledge that has been contributed to the Guidelines Color Books, including the specific subject of this book.

ARRIS	ATEME	ATT DIRECTV
British Broadcasting Corporation	BBright	Beamr
Brightcove Inc.	Broadcom	B<>COM
Comcast / NBC Universal LLC	Comunicare Digitale	Content Armor
CTOIC	Dolby	DTG
Endeavor Streaming	Eurofins Digital Testing	Fairmile West
Fraunhofer IIS	Harmonic	Huawei Technologies
InterDigital	LG Electronics	Mediakind
MovieLabs	NAB	Nagra, Kudelski Group
NGCodec	Sky UK	Sony Corporation
Xperi	Technicolor SA	Verimatrix Inc.
V-Silicon		

3. Notice

The Ultra HD Forum Guidelines are intended to serve the public interest by providing recommendations and procedures that promote uniformity of product, interchangeability and ultimately the long-term reliability of audio/video service transmission. This document shall not in any way preclude any member or nonmember of the Ultra HD Forum from manufacturing or selling products not conforming to such documents, nor shall the existence of such guidelines preclude their voluntary use by those other than Ultra HD Forum members, whether used domestically or internationally.

The Ultra HD Forum assumes no obligations or liability whatsoever to any party who may adopt the guidelines. Such an adopting party assumes all risks associated with adoption of these guidelines and accepts full responsibility for any damage and/or claims arising from the adoption of such guidelines.

Attention is called to the possibility that implementation of the recommendations and procedures described in these guidelines may require the use of subject matter covered by patent rights. By publication of these guidelines, no position is taken with respect to the existence or validity of any patent rights in connection therewith. Ultra HD Forum shall not be responsible for identifying patents for which a license may be required or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Patent holders who believe that they hold patents which are essential to the implementation of the recommendations and procedures described in these guidelines have been requested to provide information about those patents and any related licensing terms and conditions.

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7. Introduction

This book serves to cover the real world experience and guidelines for the consumption of Ultra HD content on edge devices of all types, including TVs, Operator STBs, and Retail devices.

8. Consideration of Edge Devices

The distribution of Ultra HD video services ultimately is terminated on an edge device in the home. These edge devices are there to receive the video in its distribution format and transform it to the display that the viewer watches. These take many forms.

An Ultra HD device or display is one that supports the range of technologies used in an Ultra HD Foundational service.[1] It is important to note the context of this in reading the information below, as there are optionalities to the use of some of the technologies which a service provider needs to ensure are handled correctly, for technologies that are above the display or devices Ultra HD technologies compliance.

8.1. Edge Devices

Edge Devices, or Device, is a term that describes the range of consumption devices that video and audio services are consumed with. Historically we would have called them the Television or the Set-Top-Box, but the range of different devices upon which you can consume content on or with has exploded in the last 20 years. We include Televisions in this definition as well because of the growth of Smart capabilities on TVs that enabled more than just the acquisition and display of the video and audio. The range of devices that we include are:

- Monitors
- Televisions
- Operator Set Top Boxes (STBs)
- Retail Set Top Boxes (STBs)
- Smart Televisions
- Smart Monitors
- Stick / Dongle
- Smart Displays
- Smart phones
- Tablets
- Personal Computers
- AV Receivers
- Gateway

[1] In the context of this Guideline, the use of the term Ultra HD Foundational to either a device, display or service implies it has the capabilities as defined in the Ultra HD Foundation Technologies found in section 7 of the Foundational Technologies for Ultra HD [OR01].

These devices can include the display or depend on an external Monitor or Television for consumption of video and audio, but at their most basic provide some form of interaction or transformative capability for the delivery of video and audio services.

8.1.1. Monitor

A display that normally only includes CPU and processing hardware/software for the rendering of uncompressed baseband video and audio, as well as a basic configuration user interface. The display MAY included basic video and audio processing to alter the rendering approach based upon the video and audio signal in and consumer choice.

Codec support is not applicable to a monitor (as it does not decode video provided to it), but support for color gamut, dynamic range, HDR and Audio format is meaningful when displaying content based on Ultra HD technologies. The monitor as a sink device generally will need to support the format provided by the source, or offer a degraded service.

8.1.2. Television

A display that normatively includes CPU and processing hardware/software for the rendering of uncompressed baseband video and audio, hardware/software for receiving/tuning for broadband video and audio, including whole sets of audio and video services for which the device provides basic capabilities for the display of electronic program guide information from the received service information, as well as a basic configuration user interface. The display MAY include basic video and audio processing to alter the rendering approach based upon the video and audio signals in and consumer choice. Smart TVs have generally replaced most standalone Television products.

Codec, color gamut, dynamic range, HDR format, and audio support is applicable to a Television.

8.1.3. Operator Set Top Boxes (STBs)

A decoder/receiver device that interfaces to an operator's services provided either by a traditional RF path, a private network or public network connectivity or any combination. It includes CPU and processing hardware for enabling a high quality user interface, the hardware/software for receiving/tuning for broadband video and audio, the transformation to baseband video and audio, the capability for rendering that video and audio, and MAY include

sophisticated video and audio processing to transform the video and audio into different formats based upon user confirmation and connected display capabilities.

The device normally is provided by the Operator of a service as part of the service, and may or may not work without a valid subscription to the service. The device can include significant customisation to suit the architecture and product requirements of the Operator, which may include making it unable to work with 3rd party services or have some form of limitation on what can be done without a valid subscription. The Operator may reserve ownership of the device.

There are quite a number of STB implementations used by operators from proprietary Linux based implementations through to open source Linux implementations, with additional middleware/software platform solutions such as Android AOSP, Android Operator Tier Google TV, RDK and proprietary solutions which may include Web Browsers that support HTML5 and various software frameworks including HbbTV.

Support for Ultra HD technologies is part of the Operator's specification and many of the most recent modern operator provided STBs (post 2020) comply with the Foundational Ultra HD technologies at the very least, but include a specific set of requirements as set by the operator for compliance with their specific implementation of the service.

8.1.4. Retail Set Top Boxes (STBs)

A decoder/receiver device that interfaces to available 3rd party services provided either by a traditional RF path, a private network or public network connectivity or any combination. It includes CPU and processing hardware for enabling a high quality user interface, the hardware/software for receiving/tuning for broadband video and audio, the transformation to baseband video and audio, the capability for rendering that video and audio, and MAY include sophisticated video and audio processing to transform the video and audio into different formats based upon user confirmation and connected display capabilities.

The device is acquired by the user via retail stores or services and can be tied to one particular main service provider, provide customized access to additional service providers as well as provide more open 3rd party operation with services that can be acquired through retail paths and generally an 'App Store' model. The device will work generally without a subscription to a specific service. The device is generally owned completely by the user.

There are quite a number of STB implementations in the retail space but most are based on Android TV, Android AOSP, Google TV, and singularly Apple TV. Those based on Android

AOSP additionally make use of additional platform and UI software, such as for Amazon's Fire TV.

Support for Ultra HD technologies is a very common inclusion in most recent Retail STBs, complying with Foundational Ultra HD technologies at least but including support for one or more additional Ultra HD technologies such as Dynamic HDR and/or NGA. These STBs also support HEVC by default, with many now also including support for AV1 (but not yet commonly).

8.1.5. Stick / Dongle

A decoder/receiver device that interfaces to available 3rd party services provided either by a traditional RF path, a private network or public network connectivity or any combination in a package however that allows the device to be inserted directly into the HDMI port of a display, drawing power possibly from the display or by the addition of a small external power supply. To all intents and purposes identical to the Set Top Boxes in range of support and specification. Normally however, these Sticks tend to have slightly more limited capabilities than equivalent Set Top Boxes, offering the convenience of less wiring compared to the full capability STBs. The issue of capabilities though is changing as silicon that fits into these small packages becomes more powerful.

8.1.6. Smart Televisions

A display that combines the capabilities of a Television, combined with CPU and processing hardware/software in the style of a Retail STB. In other words, the device acts as an all in one device, with access to 3rd party services in the same way. A new development in the market today is that some operators are providing 'Operator Televisions', which offer a combination of Operator and Retail STB capability as part of the Television but with an Operator specific User Interface. There has been the capability for Operator specific User Interfaces in the past through the HBBtv Operator App approach, but the latest approach is to have the actual operator provide the TV device and User Interface in one, along with a 3rd Party App Store. Smart Televisions are now the most popular display device above standard Televisions.

Codec, color gamut, dynamic range, HDR format, and audio support is applicable to a Smart Television.

It can be expected that almost all Smart Televisions support HEVC and offer 4K resolution, if they are larger in size than 32". The variation is in terms of the beyond Foundational Ultra HD Technologies. This includes the performance level of the display in terms of color gamut and

dynamic range, as well as support for dynamic HDR metadata and next generation audio capabilities.

8.1.7. Smart Monitors

A display that combines the capabilities of a monitor, combined with CPU and processing hardware/software in the style of a Retail STB. In other words, the device acts as an all in one device, with access to 3rd party services in the same way. It differs from the Smart Television primarily in that the Monitor does not generally include any RF Tuning capabilities and is optimized for being a display of a Personal Computer.

8.1.8. Smart Displays

A new type of device that offers some form of voice or touch interaction with similar functionality as a Smart Monitor but focused on providing access to information services including home control, with the addition of the ability to support 3rd party video services as well as more advanced functionality. Generally these devices offer limited video and audio processing. Examples are the Echo Show, Google Hub and Facebook Portal devices. The issue is not just with regards to Codec support, but also to do with DRM and streaming capabilities.

8.1.9. Smartphones

A portable mobile phone and communication device that offers small screen access to public network available video and audio services. Smartphones vary greatly in performance and capability depending upon generation of the device and are generally tiered in terms of high end, mid-range and low end.

Modern Apple Smartphones fall into the compliant High End category in what follows. Compatibility exists post iPhone 7 when running iOS 11 or later, with higher experience levels on iPhone 12 or later (as of 2024). Fairplay DRM alongside HLS support is mandated for this platform, requiring Multi-DRM support in your platform. For more detailed information on HEVC support in Apple Devices please refer to https://support.apple.com/en-gb/116944.

The experience on Android based devices can be more mixed away from the high end category.

Smartphones offer a wide variety of video format/codec support depending upon the capabilities of the device, which is a key issue in developing and deploying Ultra HD services alongside

standard video services. A particular issue is the encoding profile that is supported by a device, with several smartphones being limited to Main10 Profile 4.1, rather than 5.0 or 5.1.

High End devices in the current generation almost universally support HEVC decode capability, alongside standard support for AVC. A large number of high end devices additionally support HDR albeit not at 4K resolution, with many of these devices supporting 1080p or 1440p display with HDR. HDR support for playback is dependent upon the 3rd party video application taking advantage of the device capabilities. In fact many 3rd party video applications use a whitelisting and certification approach to enabling any one specific device for HDR delivery, to ensure that each service's requirements are met. HDR support is a key challenge after the codec support. High End devices also may include support for NGA alongside the support for HDR.

Mid-Range devices in the current generation also generally support HEVC decode capability, alongside standard support for AVC. However the degree of HEVC support may be limited in some way that would require tailoring of any encoded video being delivered to them. Some mid-end devices also support HDR and the number of devices doing so is increasing. Mid-End devices may also include NGA support even if they do not support HDR.

Low End devices in the current generation may support HEVC decode capability alongside standard support for AVC. However that support may be very limited, requiring strict validation of whether to deliver HEVC based video them or AVC based video. It is relatively unlikely for Low End devices to support HDR or NGA based services even if they support HEVC.

For more detailed statements with regard to base Android support for HEVC and codecs on Android Smartphones please refer to https://developer.android.com/media/platform/supported-formats.

8.1.10. Tablets

Tablets offer similar levels of functionality to Smartphones with the same grading of support depending upon whether the device is classed as High End, Mid-Range or Low End.

Modern Apple tablets have full support for HEVC decode (from 6th Generation iPad onwards, iPad Pro, iPad Air). Similarly services are targeted to be protected by Fairplay DRM and utilise HLS streaming. For more detailed information on HEVC support in Apple Devices please refer to https://support.apple.com/en-gb/116944.

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8.1.11. Personal Computers

As general computing devices, personal computers offer a software platform upon which applications may be deployed that provide access to video services.

In the past and in some very specific instances, Personal Computers have made use of native applications to disconnect themselves from any limitations of web browser based applications. However this has required specific downloads of application software that many users were reluctant to do so. Windows and Mac app stores however do make this easier but still the zero deployment approach of using web browser based applications is more popular.

The majority of services make use of web based applications that execute within the browser that a viewer is using, and thus the level of capability is very much tied to the web based application support, the particular web browser capabilities, Codec support, the GPU hardware chipset support (as it may be separate to CPU), the CPU hardware chipset support, DRM support, the streaming protocol support, and the variety of configurations of display connected to the Personal Computer that the user may have. As things have developed from the very earliest days, the combination of support is very much aligned with the PC platform capabilities.

HEVC support has been available in Intel and AMD chipsets since 2015. As applications run as web apps in browsers, the level of support and integration between the application, video player, DRM and the web browser is key to supporting the relevant codecs and format support. Modern PCs and Web Browsers on mainstream operating systems have good support, with some specific restrictions and special notes on DRM integration.

Google Chrome

- **Windows**: Limited support. HEVC support in Chrome is primarily available through the use of the operating system's native media capabilities, which means it depends on the version of Windows and installed codecs. Modern AMD, Intel and Qualcomm processors support HEVC Hardware decode support. The experience is more problematic before Intel 8th Gen and AMD Zen based APUs, where software decode would have to be enabled unless additional GPU capability was added through an add-on accelerator..
- **macOS**: Supported. Chrome on macOS supports HEVC through the operating system's native media framework. It means that modern Intel and Apple Silicon M processors have full HEVC decode capability
- **Linux**: Not supported. There is no native support for HEVC in Chrome on Linux.

Mozilla Firefox

- **Windows**: Limited support. Similar to Chrome, Firefox relies on the operating system's media capabilities. Support for HEVC is dependent on the version of Windows and installed codecs. Modern AMD, Intel and Qualcomm processors support HEVC Hardware decode support. The experience is more problematic before Intel 8th Gen and AMD Zen based APUs, where software decode would have to be enabled.
- **macOS**: Supported. Firefox on macOS supports HEVC via the native media framework of the operating system. It means that modern Intel and Apple Silicon M processors have full HEVC decode capability
- **Linux**: Not supported. Firefox does not have native support for HEVC on Linux.

Microsoft Edge

- **Windows**: Supported. Edge has built-in support for HEVC on Windows, particularly on the latest versions of Windows 10 and Windows 11 where HEVC codecs can be installed

from the Microsoft Store where the underlying hardware does not have HEVC capability in hardware.

- **macOS**: Supported. Edge on macOS supports HEVC through the native media framework of the operating system. It means that modern Intel and Apple Silicon M processors have full HEVC decode capability

Safari

- **macOS**: Supported. Safari has comprehensive support for HEVC in hardware as part of the native capabilities of macOS on modern Intel and Apple Silicon M processors.

Opera

- **Windows**: Limited support. Opera, like Chrome and Firefox, depends on the operating system's media capabilities on Windows.
- **macOS**: Supported. Opera on macOS supports HEVC through the native media framework.
- **Linux**: Not supported. Opera does not have native HEVC support on Linux.

8.1.12. AV Receivers

A device that is deployed in conjunction with devices and displays to offer audio transcode/decode and AV switching capabilities. The key aspect as it pertains to Ultra HD services, is that the AV Receiver needs to allow or not block the HDMI capabilities that support Ultra HD technologies, which means support of the relevant HDMI2.0b or later specification capabilities along with the use of the correct cabling. AV Receivers are a major source of HDMI interoperability issues due to the need for them to be inserted in the video and audio baseband signaling path.

8.1.13. Gateway

A device that offers a variety of technical features starting at its most basic level as an interface between the home consumer network and the public/private networks that deliver IP and other services to the home. However some Gateways offer additional technical capabilities, with some early devices implemented that act as an RF termination/tuner for RF based video delivery, providing a proxy conversion to IP based video delivery within the home to proprietary operator STBs or to TVs. This was not a popular approach and soon fell by the wayside. Gateways however have now evolved further through the popularity of the deployment of Multicast ABR solutions. Multicast ABR is a technical capability that is designed to allow the multicast distribution of live streams to the edge device gateway, with the implementation of a CDN

style/Proxy conversion of individual multicast streams to a standard ABR protocol presentation. Any application running on local devices would then use the Gateway as an ABR based Origin for playing back the resultant unicast stream to retail devices within the home.

8.2. Video Handling on Edge Devices

For the Devices that include a decode capability and output baseband video to a display device, there are some aspects of HDR handling that need to be taken into account. In the Green Book Table 11 [G01] there is a high level view of the combinations of SDR / HDR content and the transformations that a device can apply to the content depending upon the display capabilities. There is an extension of this that has become commonplace in Edge Devices and that is managing the consumer experience of the content and not just adapting the HDR format for the display, by outputting the maximum quality image no matter what the incoming content format is.

8.2.1. Display Policies

What does this mean in practice? It means for the Edge Device follows a policy implementation set by the device manufacturer that generally negotiates the highest resolution, dynamic range, color gamut, and frame rate for the Edge Device that the Display can support, and then auto convert the incoming content to that resolution, dynamic range, color gamut and frame rate all the time. This is targeted at reducing the chances of interoperability issues between the Edge Device and the display, and providing a consistent experience.

8.2.1.1. Problems with Display Policies

The challenge with this is several - the conversion quality can vary considerably, and the resulting transformation of the content format may introduce artifacts of the conversion, change the creative intent significantly, or even make poor decisions and down convert the content needlessly. It also introduces the challenge that the display may indicate 4K HDR mode is in operation to the viewer and mislead the consumer as to the actual quality of the video that is being delivered and experienced. What we have determined is that the majority of retail devices and some operator devices come with this ‘AutoHDR’ capability enabled by default. Not all devices offer a way of disabling or modifying this setting.

An additional impact of the policy decision to present content at the highest ‘quality’ to the display is that the display itself will take decisions on rendering the content as it is truly that format that is being presented. So for a situation in which HD SDR content (as an example) is consumed on a device connected to a 4K HDR display, the conversion via ‘AutoHDR” results in

the TV believing it is receiving 4K HDR content, and behaving as it is. This means that regardless of the ‘SDR’ nature of the content, the TV will be operating in HDR mode which in many TV displays means that it would be using significantly more energy through the backlight, even if the content is not displayed more brightly. From a sustainability perspective this is very much not optimal, in addition to the challenges that occur in the quality of the conversion. This is particularly true considering that much content that is consumed via devices on displays is not HDR in nature.

8.2.1.2. User Control of Playback

Whilst we recognise that the use of mechanisms like ‘AutoHDR’ have been advantageous in managing the user experience with early implementations of HDR displays and content services, we do recommend a different approach that some device manufacturers follow.

Firstly it should be possible for the consumer to manually configure the display configuration to what works for them during and post installation of the device/display, rather than automatically defaulting to HDR mode at all times. It may also be possible, based on the capabilities of the device and/or services, to allow the consumer to alter whether they are consuming HDR or SDR based versions of the content.

During the first setup of the device and in terms of when the screen is detected as having been changed and supports HDR capabilities, the device should test for smooth switching between SDR and HDR modes so that the default option for video playback may be ‘Follow video dynamic range stream format’. This would allow the display to operate in SDR for general operation and playing back SDR formatted content, and only output HDR when playing back HDR based content. It may also be an option for the device to force output in SDR mode (via conversion or service configuration) at all times under user control, if that is something that the user of the device wishes to.

It may also be advantageous to provide the user of the device with the capability to manually select “follow format” as the default with respect to frame rate, and/or make use of the ‘Filmmaker’ mode support derived from the content that is being displayed.

8.2.2. Future Work and Guidelines

The Interoperability Working Group is continuing to look at issues with Device Policies, and the changes that have been taking place with regard to device capabilities when sending content to displays. Sustainability has been identified as a major work area, where there is industry and Forum work underway looking at how content is processed by devices and displays to improve

the way that content is rendered with control on the reduction of energy consumption in displays, whilst maintaining visual quality.

8.3. Audio Handling on Edge Devices

There are long standing behaviors on Edge Devices with regard to Audio including pass through options from the device is not able to support a format, through to supporting the audio format. Included in that range of options is terminating and rendering the format into a supported format for the display. When this is done, there is a concern that the viewer is not experiencing the quality of the audio experience that they believe they should be receiving - seemingly supporting the higher grade format, but down converting this to a lower format due to the display not being able to support the format.

8.3.1. Future Work and Guidelines

This is an area that the Interoperability Working Group is investigating, for which the result will be documented in future editions.

9. Foundation Technology Decoders

The technical capabilities covered by decoders and services in terms of Foundation Ultra HD capability, split into Foundation Decoder Capabilities and Foundations Service Formats.

9.1. Foundation Decoder Capabilities

Table 1 and Table 2 categorizes decoders and services in terms of Foundation Ultra HD capability. Foundation decoder and service formats provide the base encoding formats for a number of enhancement features which may be implemented without causing service incompatibility with Foundation supporting devices. This will normally be described in the sections covering the enhancement features.

Table 1. Foundation Decoder Capabilities

Type No.[1]	Color Container	Resolution[5]	Frame Rate[6]	Bit Depth	HDR	SDR BT. 2020[3]	HDMI	HDCP	UHDF Foundation
1	BT.709	1080	P25/30	8	No	No	1.4	1.x	No
2	BT.709	1080	P50/60	8	No	No	1.4	1.x	No
3	BT.709	2160	P25/30	8	No	No	1.4	1.x	No
4	BT.709	2160	P50/60	8	No	No	2.0	2.2+	No
5	BT.2020	1080	P50/60	10	No	Yes	2.0	2.2+	No
6	BT.2020	2160	P50/60	10	No	Yes	2.0	2.2+	Yes
7	BT.2020	1080	P50/60	10	PQ10	Yes	2.0a	2.2+	Yes
8	BT.2020[4]	1080	P50/60	10, 8	PQ10	No	2.0a	2.2+	Yes
9	BT.2020	2160	P50/60	10	PQ10	Yes	2.0a	2.2+	Yes
10	BT.2020[4]	2160	P50/60	10, 8	PQ10	No	2.0a	2.2+	Yes
11	BT.2020	1080	P50/60	10	HLG10/PQ10	Yes	2.0b/2.1[7]	2.2+	Yes
12	BT.2020	2160	P50/60	10	HLG10/PQ10	Yes	2.0b/2.1[7]	2.2+	Yes
13	BT.2020[4]	1080	P50/60	10, 8	HLG10/PQ10	No	2.0b/2.1[7]	2.2+	Yes
14	BT.2020[4]	2160	P50/60	10, 8	HLG10/PQ10	No	2.0b/2.1[7]	2.2+	Yes

Table 1 Notes:

1. The Ultra HD Forum finds that decoder types 1, 6, and 12 (in **bold** text) comprise the vast majority of decoders, with type 12 being now the most common.

2. Decoders capable of HDR are assumed to also be capable of SDR.

3. Decoders capable of BT.2020 [3] are assumed to also be capable of BT.709 [2] at 10- and 8-bit depths.

4. *The Ultra HD Forum InterOp Work Group has found that some decoders capable of HDR/BT.2020 are capable of SDR/BT.709, but not also capable of SDR/BT.2020.

5. Decoders capable of 2160p resolution include support for 1080p resolution through up-conversion.

6. Frame rates indicated are maximum supported for the decoder and include the support for lower frame rates, i.e., 24, 25, and 30, including fractional frame rates for 24, 30 and 60.

7. Starting in 2020, decoders and displays have been introduced which make use of HDMI 2.1 and offer support beyond Foundation Decoder Capabilities including (but not limited to) higher than 2160 resolutions as well as high frame rates (HFR) at 2160 and higher resolutions. What is important to understand however is that many decoders do not support all the capabilities of the HDMI 2.1 [15] standard. This can be due to limitations of first-generation HDMI 2.1 silicon and/or design decisions not to support capabilities that require support of the higher bandwidth capabilities of HDMI 2.1. A reference to HDMI 2.1 support in a decoder always needs to be qualified as to what aspects of HDMI 2.1 is electrically supported.

9.2. Foundation Service Formats

Table 2. Foundation Service Formats

Service Format Description	Attributes					Table 1 Decoders	UHDF Foundation
	Color Container	Resolution	Frame Rate	Bit Depth	HDR		
HD SDR	BT.709	1080	P30	8	No	All	No
HDp60 SDR	BT.709	1080	P50/60	8	No	2 and above	No
UHD SDR	BT.709	2160	P30	8	No	3, 4, 6, 9, 10, 12 and 14	No
UHD SDR	BT.709	2160	P50/60	8	No	4, 6, 9, 10, 12 and 14	No
HDp60 SDR2020	BT.2020	1080	P50/60	10	No	5, 6, 7, 9, 11, and 12	No
UHD SDR2020	BT.2020	2160	P50/60	10	No	6, 9, and 12	Yes
HDp60 PQ10	BT.2020	1080	P50/60	10	Yes	7 and above	Yes
HDp60 HLG10	BT.2020	1080	P50/60	10	Yes	11 and above	Yes
HDp60 HLG10*	BT.2020	1080	P50/60	10	Yes	11 and above (HDR), 5 through 10 (SDR)	Yes
UHD PQ10	BT.2020	2160	P50/60	10	Yes	9, 10, 12, and 14	Yes
UHD HLG10	BT.2020	2160	P50/60	10	Yes	12 and 14 (HDR)	Yes
UHD HLG10*	BT.2020	2160	P50/60	10	Yes	12 and 14 (HDR), 6, 9, and 10 (SDR)	Yes

Table 3 Notes:

*Indicates the Service Format signals HLG10 using the SDR/BT.2020 backward compatible method.

9.3. Additional Technology Decoders

Support beyond Foundation in Decoders is not universal, with many more permutations and combinations due to commercial and technology decisions being taken by the ODM/OEM, the operator, or the distributor of the device. It is also important to note that the usage of a format is also dependent on the application that is managing the consumption of content, so the support may be available in the device but not in use due to application decisions. What is important to note is that there are devices in the market that support Foundation decode capabilities and any

combination of the additional technology capabilities, all dependent on the choices made by the ODM/OEM, operator, distributor and application designer. Beyond HDR formats, those additional technologies that impact decoders includes NGA and HFR

Due to adoption by Google in their later variant Android TV based devices, it is relatively common to find devices supporting both Dolby Vision and HDR10+.

9.3.1. Dolby Vision

In the wild, Dolby Vision capabilities are dependent on the profile support integrated into the device. More detailed information is available in Section 7.1.1 of the Yellow Book [Y01].

Dolby Vision support indicates compliance with Dolby Vision Profile 5. This profile offers no backwards compatibility and requires the content, decoder and display all to support the same profile and content.

Dolby also has other profiles that may be available on a device to support Dolby Vision.

This includes Dolby Vision over Broadcast as described for DVB which is based on Dolby Vision Profile 8.1. This profile is a PQ10 base format with the addition of SMPTE ST.2094-10 [86] metadata, amongst other things, and offers backward compatible support for devices that may receive the format. Foundation based HDR10 capable devices are able to correctly decode and display content produced for this profile as HDR10 content.

Mobile devices, specifically Apple iPhone and iPad, also make use of Dolby Vision supporting Dolby Vision Profile 8.4, through content that is captured off the built in cameras. This is a HLG10 base format with the addition of SMPTE ST.2094-10 metadata. The use of this profile means that supporting devices correctly decode the content in full Dolby Vision, but it also offers two step down capabilities: supporting HLG10 HDR decode on devices that support HLG10, and SDR decode on those devices that do not support HDR.

Dolby Vision has a broad adoption by content providers, devices and displays.

9.3.2. Advanced HDR

Advanced HDR makes use of three main variants, two of which are detailed in the Section 7.1.3 in the Yellow Book [Y02]. The additional variant is SL-HDR3 which makes use of an HLG10 base layer.

Advanced HDR has been adopted as part of some displays used in several markets, but more precisely it can be found in ATSC 3.0 (where it is an option) and Brazil TV3.0 (as detailed in the Indigo Book Section 12.2.4 [I01]) based devices.

9.3.3. HDR10+

HDR10+ is a format consisting of a PQ10/HDR10 base layer combined with SMPTE ST.2094-40 metadata which serves to enhance the rendering of HDR10+ based content on HDR10+ supporting devices and displays. It was originated by Samsung and has some adoption on other devices (notably Android TV based) and some content providers. More details may be found at the Adopter Website (https://hdr10plus.org/).

9.3.4. NGA

NGA based support is quite widely deployed on devices at this point albeit with some transition approaches being in use. Dolby Atmos based NGA is found both in its E-AC-3 w/JOC [35] and full AC4 variant on a wide range of devices being deployed. EAC3 deployment still dominates but the adoption of AC-4 [56] is growing. MPEG-H has also been deployed in a lesser number of devices, but is required for support in a number of regional deployments such as TV 3.0.

9.3.5. HFR

With the adoption of HDMI 2.1 [15], HFR capabilities on displays have become more commonplace starting in 2022, but less so on devices. The deployment of HFR capability is being driven by gaming device support more than any deployment of HFR video content, which explains the slower growth in devices associated with video services. Gaming is seen as being the key commercial justification for the higher implementation cost of full HDMI 2.1 based support in displays.

10. Decoding and Rendering

This section covers guidelines for implementation of decoding capabilities in the consumer player device, picture processing capability of the consumer display device as well as the interface between the consumer player device and the consumer display device. There are two possible architectures for decoding and rendering in the consumer home: 1) STB decoder connected to a display, and 2) integrated decoder/display.

The extent to which the consumer decoder or display is able to switch between SDR/BT.709 [2] and PQ10/HLG10 [5] content or switch between PQ10 and HLG10 seamlessly is not proven, nor is it specified by any standards. It is recommended that service providers employ conversions as needed to ensure that program content, interstitial material, and graphic overlays (bugs, crawls, etc.) within in a given program are either entirely SDR/BT.709 or entirely PQ10 or entirely HLG10, to the extent possible.

This section addresses equipment that is compatible with Foundation Ultra HD content streams. Note that decoders that support only 8 bits are not considered Foundation Ultra HD decoders. (These were the first generation of decoders.)

10.1. Decoding

Foundation Ultra HD consumer decoder devices have the capabilities to:

- Decode HEVC, Main 10 Profile, Level 5.1
- Process video bit depths of 10bit or higher
- Process BT.2020 [3] system colorimetry
- Process PQ transfer characteristics
- Process HLG transfer characteristics
- Process HDR10 content (with or without metadata)
- Decode multi-channel Dolby AC-3 [29], E-AC-3 [35], DTS-HD, HE-AAC and AAC-LC audio
- Decode closed captions and subtitles per CTA- 608 [18] /708 [19], ETSI 300 743 [20], ETSI 300 472 [21], SCTE-27 [22], or IMSC1 [23]
- Ignore enhancement technologies that are layered upon foundation technologies
- For the STB-display architecture, the STB also supports the following:
    - Output Interface – at least HDMI 2.0a/b [15][2]

[2] Note that HLG transfer function requires at least HDMI2.0b output interface

- Optionally able to transmit ST 2086 [10] metadata, MaxCLL, and MaxFALL to the connected display device

10.2. Rendering

The characteristics of Foundation Ultra HD consumer display devices differ significantly from those of professional displays used to grade and master the content. These characteristics include luminance range, color gamut, screen size (smartphone, tablet, TV), and more. In order to compensate for these differences, Foundation Ultra HD consumer display devices are capable of processing incoming Foundation Ultra HD content so that the rendered video reproduces the creative intent as optimally as possible, for example by appropriate color volume transformation of an HDR/WCG video signal to the display panel.

Foundation Ultra HD consumer rendering devices have the capabilities to:

- Process PQ transfer characteristics
- Process HLG transfer characteristics
- Process HDR10 (with or without metadata)
- Process BT.2020 [3] system colorimetry
- Render 60p frame rates
- Render content having 2160p or 1080p (with HDR) spatial resolution (up or down conversion of resolution to fill display is required)
- Process multi-channel 5.1 channel surround sound
- Optionally able to render Atmos immersive soundtracks delivered by E-AC-3+JOC [35]
- The Display also supports the following:
  - Input Interface – at least HDMI 2.0a/b [15][3]
  - Transmission of Extended Display Identification Data (EDID) information including peak and minimum luminance
  - Transmission of supported EOTFs
  - (Optional) Transmission of RGB primaries

10.3. Overlays Inserted at the Consumer Device

Closed captions, subtitles and graphic overlays may be rendered by a STB, a display connected to a STB, or an integrated decoder/display. In the case of the STB-display architecture, it is

[3] Note that HLG transfer function requires at least HDMI2.0b input interface

possible that both the STB and the display are rendering overlays at different times or simultaneously (e.g., STB rendering an EPG and the display rendering a volume control indicator).

Several specifications regarding closed captioning and subtitles are based on BT.709 [2] system colorimetry and SDR. However the DVB ETSI EN 300 743 [20] allows the subtitle services to provide the CLUT for rendering into WCG and HDR. When overlaying closed captions and/or subtitles onto BT.2020 [3] system colorimetry and HDR video, Foundation Ultra HD decoders should remap RGB values of closed captions and/or subtitles as needed to ensure that color shifts do not occur while mixing two elements having different system colorimetries and/or dynamic ranges.

Similar care should be taken when displaying graphics, EPGs, user interface overlays and so on.

10.4. Considerations for Ultra HD Technologies beyond Foundation Ultra HD

Service delivery has to account for the format support of the decoder/display device through a variety of strategies. Foundation Ultra HD formats are generally supported on all Foundation Ultra HD decoder/displays but deploying additional Ultra HD Technologies may require one or more strategies to ensure continued operation of Foundation Ultra HD decoder/displays. These strategies can be formalized as follows, and it should be noted that each additional Ultra HD technology can make use of one or more of these strategies, which is described in the relevant section of the additional Ultra HD technology:

10.4.1. Simulcast

Sending enhanced Ultra HD technology-based service separately from a Foundation Ultra HD technology-based service where the content of the two streams is essentially identical, which can be used when the enhanced Ultra HD technology-based service offers no backwards compatibility with Foundation Ultra HD decoder/displays

Example: A service that includes an NGA Audio program, and also makes available an alternate audio program using a Foundation, channel-based format, with the correct audio program selected by the client device.

10.4.2. Backward compatibility

The enhanced Ultra HD technology-based service is inherently supported by Foundation decoder/displays, normally with a graceful degradation in experience or functionality on the display. The degree of how ‘graceful’ the degradation is, is not well defined here but may result in noticeable differences. It is for the service operator to determine if the difference is acceptable, or whether additional processing in the workflow would be necessary. The alternative would be simulcast.

Example: A Linear Broadcast in HLG10 that is decoded by all displays and rendered by HDR/BT.2020 [5] decoder/displays as HDR and by SDR/BT.2020 [3] decoder/displays as SDR.

10.4.3. Optional Capabilities

The enhanced Ultra HD technology is delivered along with a Foundation Ultra HD based service as an optional component that is not identifiable or usable by a Foundation Ultra HD technology-based device. Care is taken to ensure that the optional capability absence does not affect the consumption of the service negatively.

Example: An SL-HDR2 encoded service, which comprises a PQ10-encoded video in conjunction with ST.2094-20 [145] /ST-2094-30[145] metadata, which an SL-HDR2 capable decoder/display will render fully, and a PQ10 capable decoder/display will render as PQ10 without the enhancement of the dynamic metadata.

10.4.4. Layering

The enhanced Ultra HD technology-based service is delivered alongside a base layer that is Ultra HD Foundation compliant and the decoder/display processes the required combination of layers in a way suited to its capabilities to achieve the enhancement.

Example: Delivery of a backward compatible HFR video that is encoded using a base layer standard frame rate elementary stream and a secondary enhancement layer elementary stream that contains the additional frames to allow an HFR capable decoder/display to re-multiplex the two streams together to render the HFR video. A non-HFR capable decoder/display would identify and render only the base layer standard frame rate video, ignoring the additional frames.

10.4.5. Service Provider Down-conversion

The enhanced Ultra HD technology-based service is converted to a Foundation Ultra HD service, generally with the loss of enhancements.

Example: An operator receiving a SL-HDR2 encoded linear service for distribution, undertaking a down conversion to a HLG10 encoded service for distribution.

10.4.6. Device Down-conversion / Up-conversion

The enhanced Ultra HD technology-based service is down converted (or, in the case of Foundation based services on enhanced Ultra HD based devices, up converted) to a format suited for final display, normally with loss of enhancement in down-conversion, or with a simulacrum of an improvement in up-conversion.

Example: An operator distributing an SL-HDR1 encoded service to an STB that can detect the capability of the display via an HDMI interface. The STB applies the SL-HDR1 metadata to supply HDR/BT.2020 to HDR/BT.2020 displays and does not apply the SL-HDR1 metadata to supply SDR/BT.709 displays.

11. Format Interoperability

There are a number of requirements for format interoperability, when considering the needs of broadcasters or service providers working with both Foundation Ultra HD and HD (and even SD) content. One example of this is Backward Compatibility, i.e., the means of delivering a Foundation Ultra HD service to a legacy consumer device, in such a way that it can be viewed at some level of acceptable quality on an SDR/BT.709 display.

Backward compatibility that conveys the full creative and artistic intent of the original Foundation Ultra HD content is not attainable. Foundation Ultra HD gives producers, camera operators, directors, editors, production designers, etc. more creative possibilities. Since legacy screens will not be able to display the full resolution, dynamic range and color gamut of the original production, some of the original creative intent will be lost.

Foundation Ultra HD services are distributed via DTT, OTT or MVPD.

This section addresses Foundation Ultra HD backward compatibility for the installed base of SDR 2160p TVs, both BT.709 [2] and BT.2020 [3] displays. Thus, not all facets of Foundation Ultra HD content are considered for Backward Compatibility in Foundation Ultra HD. Specifically:

- Spatial resolution down-conversion is not in scope; only 2160p-capable decoder/displays for Foundation Ultra HD content are included
- Frame rate down-conversion is not in scope; only 50/60 Hz-capable decoder/displays for Foundation Ultra HD content are included
- HDR and WCG are the primary parameters being considered for Foundation Ultra HD backward compatibility

Backward compatibility for OTT and MVPD services involves either:

- For HLG10:
  - HLG10 technology is designed to produce acceptable results using the same content stream on both HDR and SDR devices, provided that the SDR device can process BT.2020 system colorimetry (nb. not valid for BT.709 only devices). Validation of the quality of the SDR output has been investigated by the EBU, IRT, RAI and Orange Labs (see EBU Tech Report 038 [88]). In the event that the SDR rendering of HLG10 content does not meet an operator's requirements, schemes similar to those proposed for HDR10/PQ10 may be used (see below).

- For HDR10 or PQ10
    - Simulcasting multiple broadcast streams, one in HDR10 or PQ10 and the other in SDR/BT.709 (see Section 11.2.), and/or
    - Using a STB that can decode the Foundation Ultra HD stream and deliver material suitable for an HDR/WCG, HDR/BT.709, or SDR/BT.709 display. In the case of HDR10, the STB may be able to take advantage of the HDR10 static metadata (see Section 7.2 in the Blue Book [B01]), when present, in creating the down-conversion. Ideally, the Foundation Ultra HD STB is capable of serving any of these displays so that when a consumer decides to take advantage of HDR services, only a new display is needed.

Creating a backward compatible version of the content that is acceptably rendered on a SDR/BT.709 [2] display may take place at various points in the supply chain between production and the display:

- Content producers can generate both HDR/WCG and SDR/BT.709 versions, applying creative intent adjustments to both versions. This results in the highest quality conversion but requires time and resources and both versions must be carried throughout the supply chain. This option may not be practical for Live content workflows.
- Professional equipment can down-convert HDR/WCG to SDR/BT.709 with or without the benefit of creative adjustments. This equipment may be sophisticated and thus may be the best option if automated conversion is necessary.
    - HDR10 static metadata (Blue Book, Sec 7.2 [B01]), when present, may assist this process.
- Consumer equipment (i.e., STB) can down-convert HDR/WCG to SDR/BT.709 without the benefit of creative adjustments. This equipment is likely to be less sophisticated than professional equipment but may be a viable alternative when it is impractical to offer multiple versions of the content to the consumer premises.
    - HDR10 static metadata, when present, may assist this process.

11.1. Legacy Display Devices

In Foundation Ultra HD, the Ultra HD Forum is considering legacy display devices that are connected to the MVPD STB or are receiving a suitable unicast stream from the OTT provider. In the latter case, the OTT provider offers a suitable stream, and it is up to the provider to determine which devices it can support. An STB that can ingest a Foundation Ultra HD stream

and output a modified stream that a legacy display device can render is considered. The variety of legacy display devices that a STB can accommodate varies by product as does the quality of the down-conversion.

For example a backwards compatible distribution solution or STBs capable of down-conversion can address first-generation 2160p/1080p SDR televisions, i.e., devices that can render resolution content with BT.709 [2] or BT.2020 [3] color gamut but only in SDR. In the absence of one of these solutions, a direct IP stream can be used to address HDR TVs, e.g., using an embedded HTML5 [32] or RVU client[4] that extracts the received broadcast stream and re-encapsulates it into an IP stream that can be transmitted to a TV via a Local Area IP Network. Note that currently some Ultra HD displays are capable of accepting BT.2020 content, however at this time no direct view display is available that is capable of rendering the full gamut of colors in the BT.2020 system colorimetry. It is known that in these cases, the display/device employs color volume transform tailored to its particular display characteristics, and thus these devices are considered BT.2020-compatible for the purpose of this discussion.

11.2. Down-Conversion at the Service Provider

This option may be employed by OTT providers or by MVPDs. With this method, providers offer both Foundation Ultra HD and legacy versions of the service and send the appropriate stream to devices (unicast) or simulcast both streams. In general, providers that use DASH as a transport method may use unicast and providers that use MPEG-2 TS may use simulcast. The variety of legacy devices served is a function of how many different streams a given service provider chooses to make available. This method may require content producers to deliver multiple versions of the content to the service provider and/or utilize professional conversion equipment at the headend (see Blue Book Section 8 [B02]).

The below diagram illustrates this method of backward compatibility.

[4] See https://rvuproject.org/

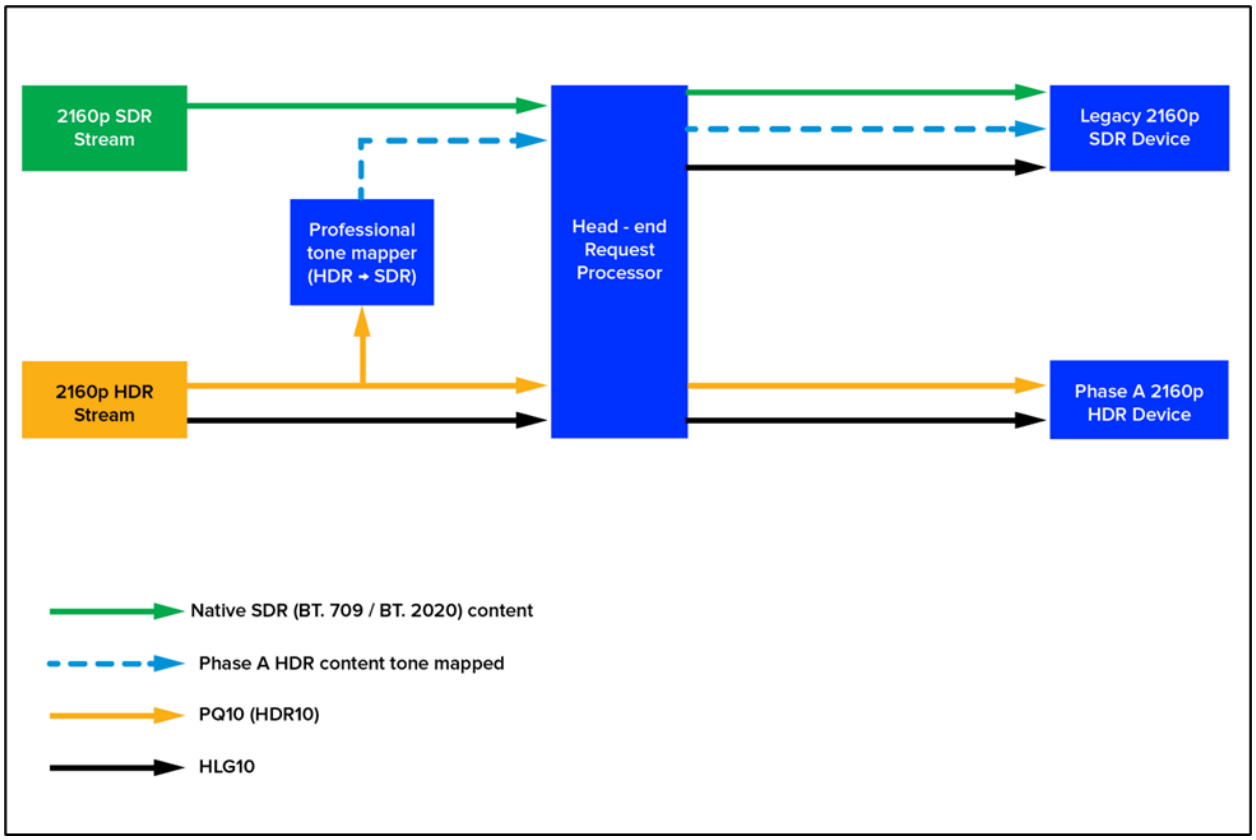

Figure 1. Down-conversion at the Headend

In the above diagram:

1. Operator receives legacy and Foundation Ultra HD content from different content sources.

2. Operator can convert* Foundation Ultra HD streams for legacy 2160p SDR devices.

3. Device requests content from headend based on its capabilities.

4. Headend request processor provides appropriate stream.

*Note that conversion could occur upstream of the headend; i.e., the content producer could provide the operator with both SDR and HDR versions of the content.

11.3. Down-conversion at the STB

This option may be employed in Foundation Ultra HD by MVPDs that prefer not to use the bandwidth required for offering multiple unicast streams, such as via switched digital video technologies, or multiple simulcast streams. In this case, the STB is capable of decoding a Foundation Ultra HD stream and is also capable of down-converting the content. As stated above, there are compromises with down-conversion of Foundation Ultra HD content and service providers should test the quality of the output for acceptability. Normal industry best practice is to provide separate non-Ultra HD technology streams at the head for legacy SDR displays and to rely on resolution upconversion only at the STB. In addition converting to SDR on the device also has sustainability questions of multiple conversions (xN multiplier) compared to single conversion at the headend.

Although there is no standardized method of down-converting BT.2020 [3] to BT.709 [2], it is expected that some STBs may have this capability. STBs may also have the capability of down mapping PQ10 or HDR10 to SDR. The diagram below illustrates this method.

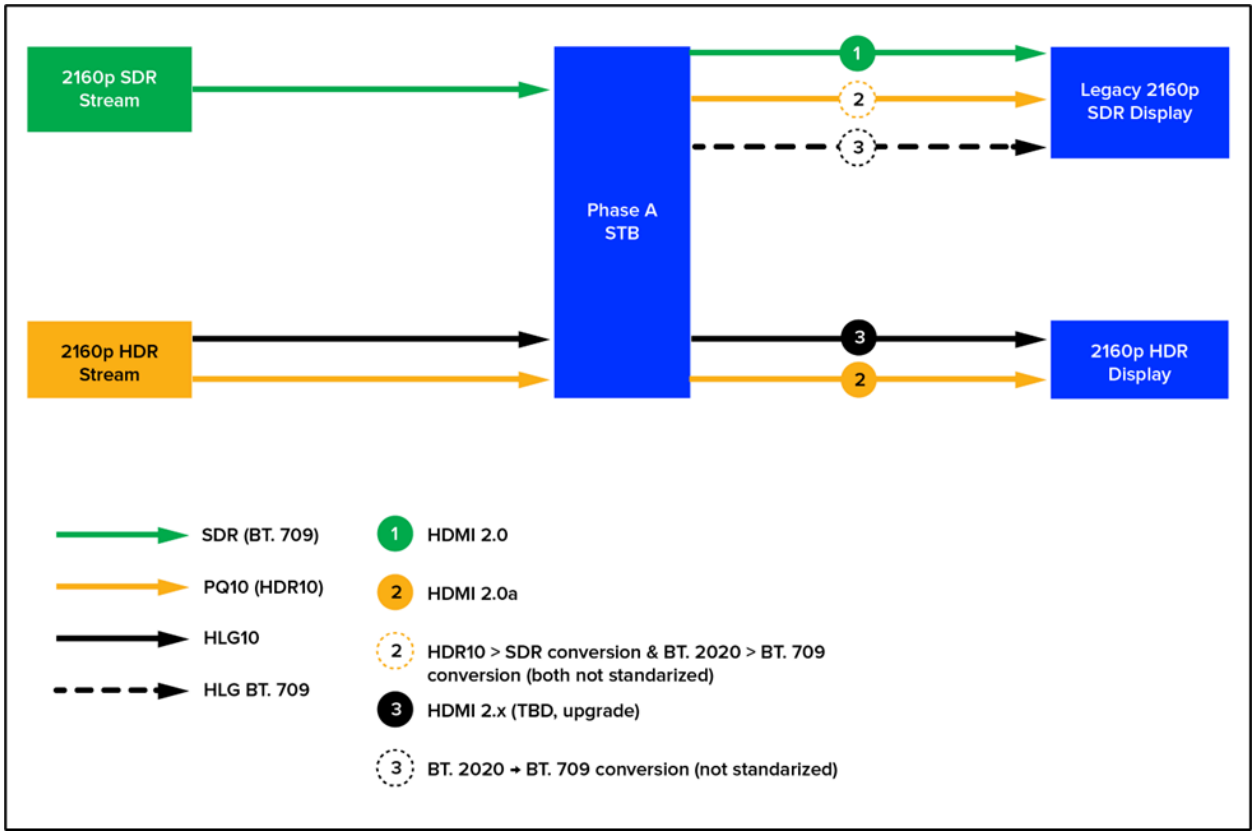

Figure 2. Down-conversion at the STB

Details:

- The Foundation Ultra HD STB supports HEVC, Main 10 Profile, Level 5.1 [26], BT.2020 [3], and HDMI 2.0a and optionally IP output.
- In this example, the legacy 2160p SDR display supports BT.709 [2] but does not support BT.2020.
    - Therefore, in the diagram, the Foundation Ultra HD STB would convert the video from BT.2020 to BT.709 before transmitting it to the legacy 2160p SDR display.
    - Note that some legacy 2160p SDR displays may support BT.2020 and for these displays, a Foundation Ultra HD STB does not need to convert from BT.2020 to BT.709 before transmitting to the TV.

11.4. Spatial Resolution Up-conversion of Legacy Services

This option may be employed in Foundation Ultra HD by MVPDs that prefer not to use the bandwidth required for offering multiple unicast streams, and when Foundation Ultra HD STBs are not be able to convert a Foundation Ultra HD stream to an appropriate format and/or with sufficient quality for display on a legacy 2160p SDR display. Foundation Ultra HD STBs (as well as legacy 2160p SDR displays) are expected to have the capability of upscaling 720p/1080i/1080p SDR channels to 2160p resolutions. This option requires simulcasting; however, the 720p/1080i/1080p SDR stream/service often already exists, e.g., during a transition period. In this case, the legacy 2160p SDR display gets the legacy stream and up-converts the spatial resolution to 2160p. Only the 2160p HDR display gets the Foundation Ultra HD stream. There are compromises with up-conversion of 720p/1080i/1080p content and service providers should test the quality of the output for acceptability.

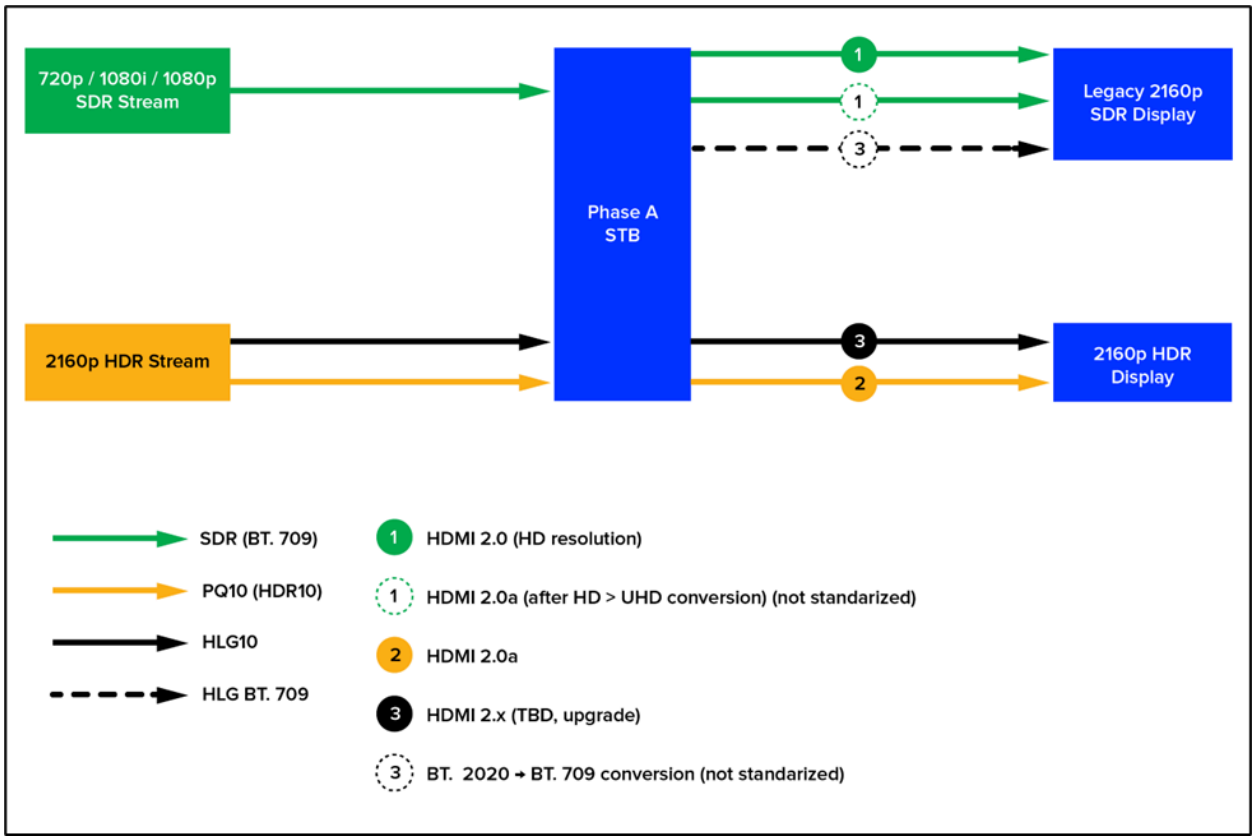

Figure 3. Spatial Resolution Up-conversion of Legacy Services

Details:

- The Foundation Ultra HD STB decodes the 2160p HDR stream when connected to 2160p HDR displays.
- The Foundation Ultra HD STB decodes the 720p/1080i/1080p SDR stream when connected to legacy 2160p SDR displays. The STB can either transmit the decoded 720p/1080i/1080p SDR video or convert the 720p/1080i/1080p SDR video to 2160p SDR video before transmitting it to the legacy 2160p SDR display.
- Note that SDR to HDR conversion, if needed, is best performed in the display device rather than in the decoder device.

11.5. Interoperability of Atmos Immersive Audio

For emission of Atmos Channel-based or Object-based Immersive Audio, an E-AC-3+JOC encoder with ETSI TS 103 420 [35] functionality is required. Internally, the encoder will create a backward compatible 5.1 channel version rendered from the 7.1.4 (or 7.1.2 or 5.1.2 or 5.1.4) input. This 5.1 channel render is E-AC-3 coded as normal and information about the render, as described in ETSI TS 103 420, is also carried. Legacy E-AC-3 decoders will reproduce the backward compatible base surround program while advanced E-AC-3 decoders, compliant with ETSI TS 103 420 will reproduce the full 7.1.4 (or 7.1.2 or 5.1.2 or 5.1.4) immersive audio program.

11.6. Considerations for Ultra HD Technologies beyond Foundation Ultra HD

Foundation Ultra HD service formats can be rendered by Foundation Ultra HD decoder/displays, as well as by decoder/displays that offer additional Ultra HD Technology capabilities.

When deploying services that make use of additional Ultra HD Technologies (beyond Foundation Ultra HD) care needs to be taken to ensure that all devices are supported using one or more of the strategy approaches described in Section 10.4.. The selection of the strategy being selected depends upon the nature of the additional Ultra HD technology and the characteristics of the service that the provider wishes to deploy.

12. Real World Device Capabilities

There are quite a number of different edge devices as detailed in Section 8.1. of this document. It is important to consider what each of these devices does and how they can influence the processing of video produced using Ultra HD technologies, in standalone and in combination with the edge devices that they also connect to. There are a large number of different devices both Operator and Retail, and we currently reproduce only a small number of real world devices as examples of capability.

This is described in this section and will be further expanded upon in future editions of this document.

12.1. Examples of TV Set Capabilities

Referring to the TV manufacturers' description of HDR support on their own web sites (beware, this is region dependent, as different SW are available in Americas, Europe & Asia in general)

Table 3. TV Set Capabilities

Brand	Reference		Support
Sony	https://www.sony.com/electronics/support/articles/00161421	UHD and HD models support HDR from 2017 onwards	HDR10, HLG, DV
LG	https://www.lg.com/us/experience-tvs/hdr/what-is-hdr	All 2017 and later UHD and HD models with HDR also support HDR.	HDR10, HLG, DV, SL-HDR1
Vizio	https://support.vizio.com/s/article/HDR-High-Dynamic-Range?language=en_US	Some 2016 models and all 2017 and later UHD models support HDR.	HDR10, HLG, DV
Samsung	https://www.samsung.com/global/tv/blog/what-is-hdr-and-why-is-it-the-future-of-4k-tv/	Mid-2016 and later VIZIO SmartCast UHD HDR TVs (P, M, E series) support HLG.	HDR10, HLG, HDR10+
Roku TV (Hisense TCL, etc)	https://support.roku.com/article/115007289948-what-is-hdr-	All TCL 4K TVs after 2018 support HDR.	HDR10, (some) DV

12.2. Examples of Retail STB Capabilities

Referring to the retail manufacturers' description of HDR support on their own web sites. Note the HDR supported is on the 2020 models onward, however different capabilities are offered over the model years and there is no documentation on the backward compatibility of older devices, thus one has to test if earlier models support the HDR modes.

Table 4. Example Retail STB Capabilities

Type	Device	Support HDR	Reference
Amazon Fire	*Fire TV* Edition *4K*	DV[1], HDR10, HDR10+, HLG	https://developer.amazon.com/docs/fire-tv/device-specifications-fire-tv-stick.html?v=ftvstick4k
Amazon Fire	*Fire TV Cube*	DV[1],HDR10, HLG	https://developer.amazon.com/docs/fire-tv/device-specifications-fire-tv-cube.html?v=ftvcubegen2
Android TV	Chromecast w/Google TV Nvidia Shield TV	HDR10, HDR10+, DV HDR10, DV	https://en.wikipedia.org/wiki/Chromecast#Chromecast_with_Google_TV https://en.wikipedia.org/wiki/Nvidia_Shield_TV
Apple TV (2)	Apple 4K	DV[1], HDR10, HLG1	https://support.apple.com/en-us/HT208074
Roku 4K	Roku 4K	DV[1], HDR10, HLG10,	https://www.roku.com/products/roku-tv/ picture-quality
Chromecast	Ultra	DV[1], HDR10, HLG1	https://developers.google.com/cast/docs/media

Table 4 Notes:

(1) DV= Dolby Vision

(2) As of this publication, Apple TV devices support HLG10 HDR up to 2160p/60 although this does not get exposed by applications.

Table 5. Example Retail STB HDR Support

Device	Max Res.	Max Framerate	HDR	Video Codec	Video Signaling	Audio Codec[4]	Packaging
FireTV Edition *4K*	2160	24/59.94	DV, HDR10, HDR10+, HLG	HEVC	SEI [(2)]	E-AC-3 w/JoC (Atmos)	HLS/DASH
FireTV Cube	2160	60	DV HDR10	HEVC	SEI	E-AC-3 w/JoC (Atmos)	HLS/DASH
FireStick 4K	2160	60	DV HDR10	HEVC	SEI	E-AC-3 w/JoC (Atmos)	HLS/DASH
Android TV STB	2160	24/59.94	HDR10, HLG	HEVC	SEI		HLS/DASH
AppleTV 4K [(1)]	2160	24/59.94	DV HDR10, HLG	HEVC	SEI	E-AC-3 w/JoC (Atmos)	HLS/DASH
Roku 4K	2160	24/59.94	DV HDR10, HLG	HEVC	SEI	E-AC-3 w/JoC (Atmos)	HLS/DASH

Device	Max Res.	Max Framerate	HDR	Video Codec	Video Signaling	Audio Codec[4]	Packaging
Chromecast Ultra	2160	24/59.94	DV, HDR10,	HEVC	SEI		HLS/DASH
Nvidia TV Shield	2160	60	DV, HDR10,	HEVC	SEI	E-AC-3 w/JoC (Atmos)	HLS/DASH
Nvidia TV Shield Pro	2160	60	DV, HDR10,	HEVC	SEI	E-AC-3 w/JoC (Atmos)	DASH
Xbox One X	2160	60	DV, HDR10,	HEVC	SEI	E-AC-3 w/JoC (Atmos)	DASH
Xbox One S	2160	60	DV, HDR10,	HEVC	SEI	E-AC-3 w/JoC (Atmos)	DASH

Table 5 Notes:

(1) Currently, Apple TV devices support HDR up to 2160p60fps using HLG10.

(2) HLG requires a VUI message for some backward compatibility modes

(3) ISO/IEC 14496-15 - Carriage of network abstraction layer (NAL) unit structured video in the ISO base media file format [28]

(4) Audio codecs beyond legacy stereo and multichannel codecs (ie, AC-3, AAC, HE-AAC, DTS-HD)

13. Real World Foundation Ultra HD Deployments

This section describes several “real world” use cases of Foundation Ultra HD deployments. The Ultra HD Forum gratefully acknowledges the many organizations that contributed their experiences to this document.

13.1. CBS and DirecTV Major Golf Tournament

Thanks to CBS and DirecTV for providing this information to the Ultra HD Forum about this workflow.

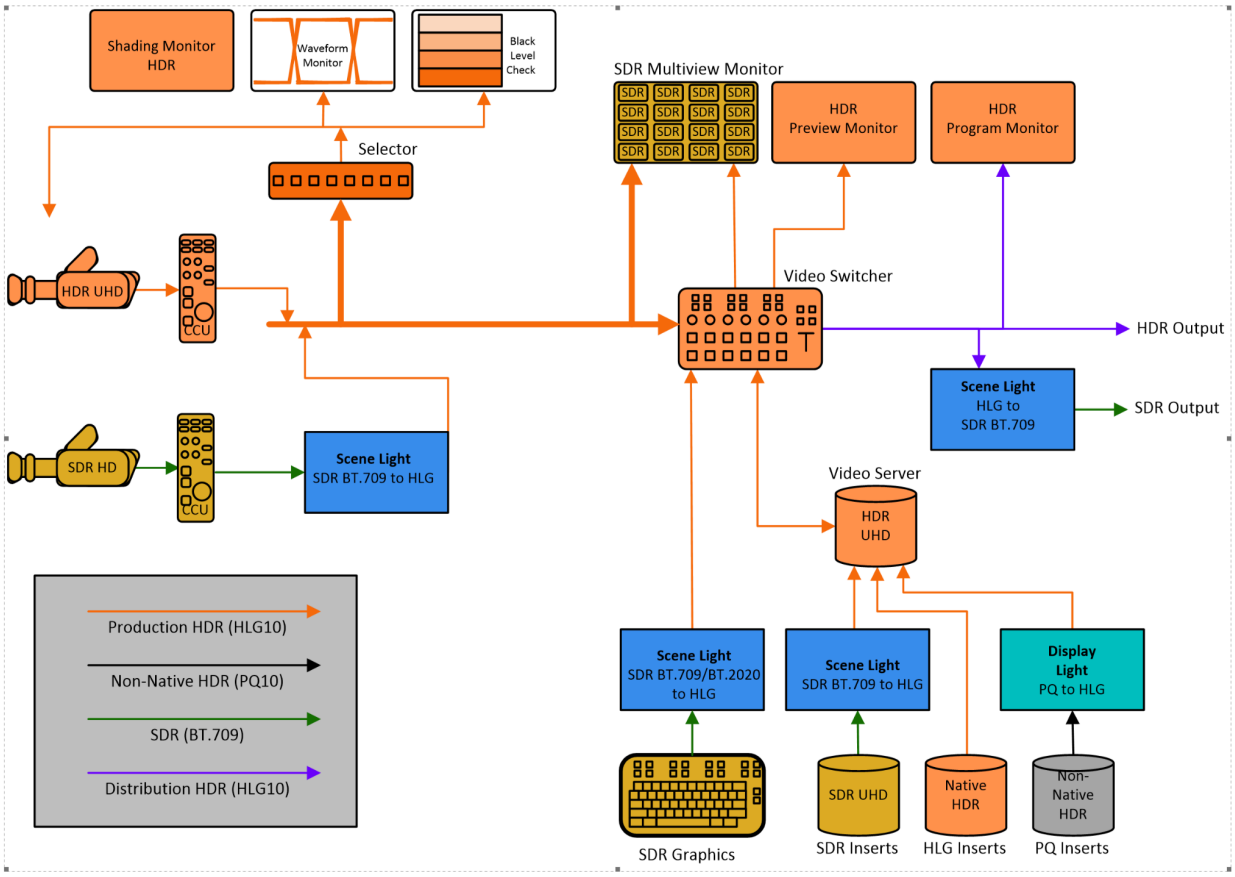

Figure 4. CBS and DirecTV Major Golf Tournament

For the production illustrated in this diagram, five holes of a golf course were captured in 4K HDR using Sony 4300 cameras operating in BT.2100 [5] HLG mode. HDR content is mastered at 1,000 cd/m^2, with BT.2020 [3] color.

The remaining elements of production were captured in SDR.

The video server shown in the lower right of the diagram is used for replays and for inserting motion graphic elements. SDR interstitials and SDR graphics are inserted in a “Scene light” manner and switched through the Video Switcher. Graphics, legacy SDR inserts and interstitials are native SDR and are converted to HDR with 100% SDR mapped to approximately 75% HLG. There is no highlight expansion of SDR sources.

An SDR version of the program is created as is shown in the “SDR Output” source on the right side of the diagram.

13.2. Amazon Major Parade

Thanks to Amazon for providing information to the Ultra HD Forum about this workflow.

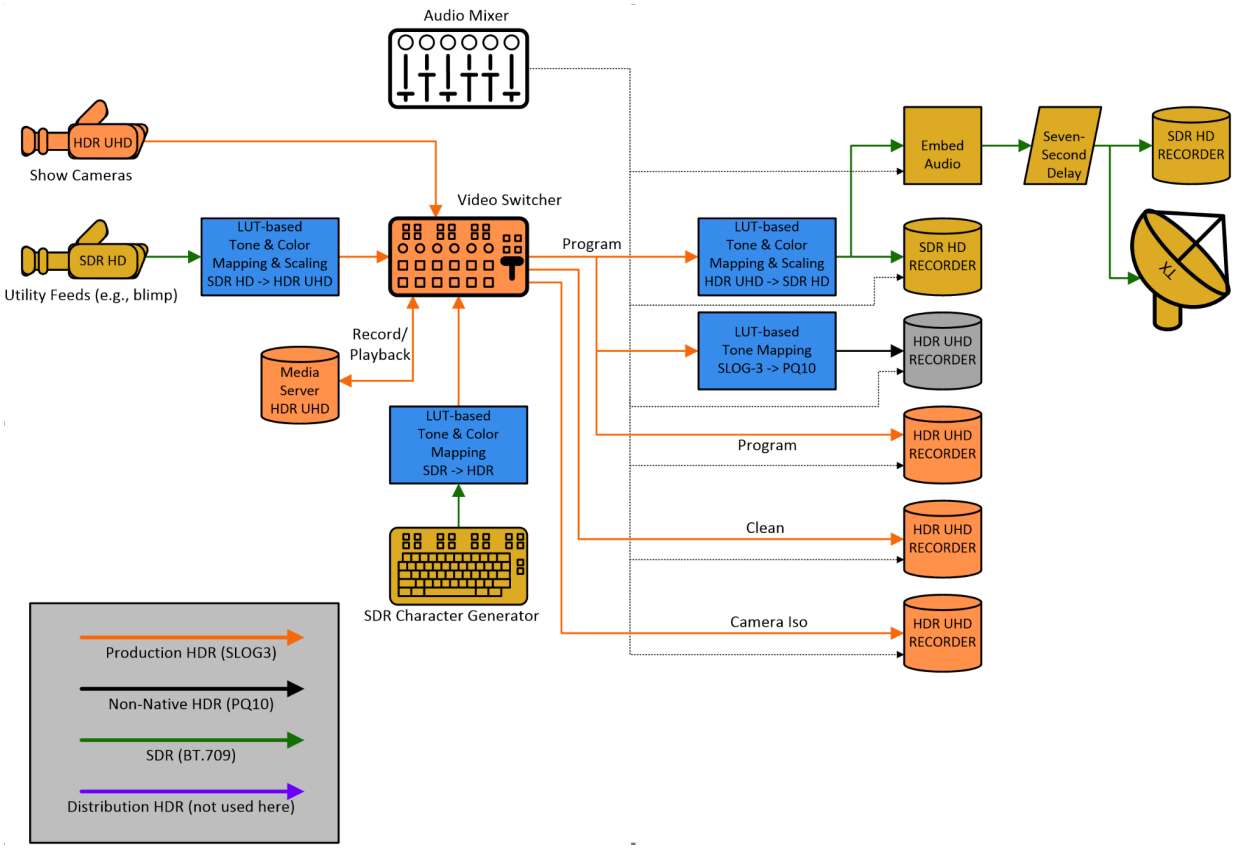

Figure 5. Amazon Major Parade Workflow

13.3. NBCUniversal Olympics and 2018 World Cup

Thanks to NBC Universal (NBCU) for providing information to the Ultra HD Forum about their “production HDR” to “PQ Distribution HDR” for linear (live) and VOD workflows.

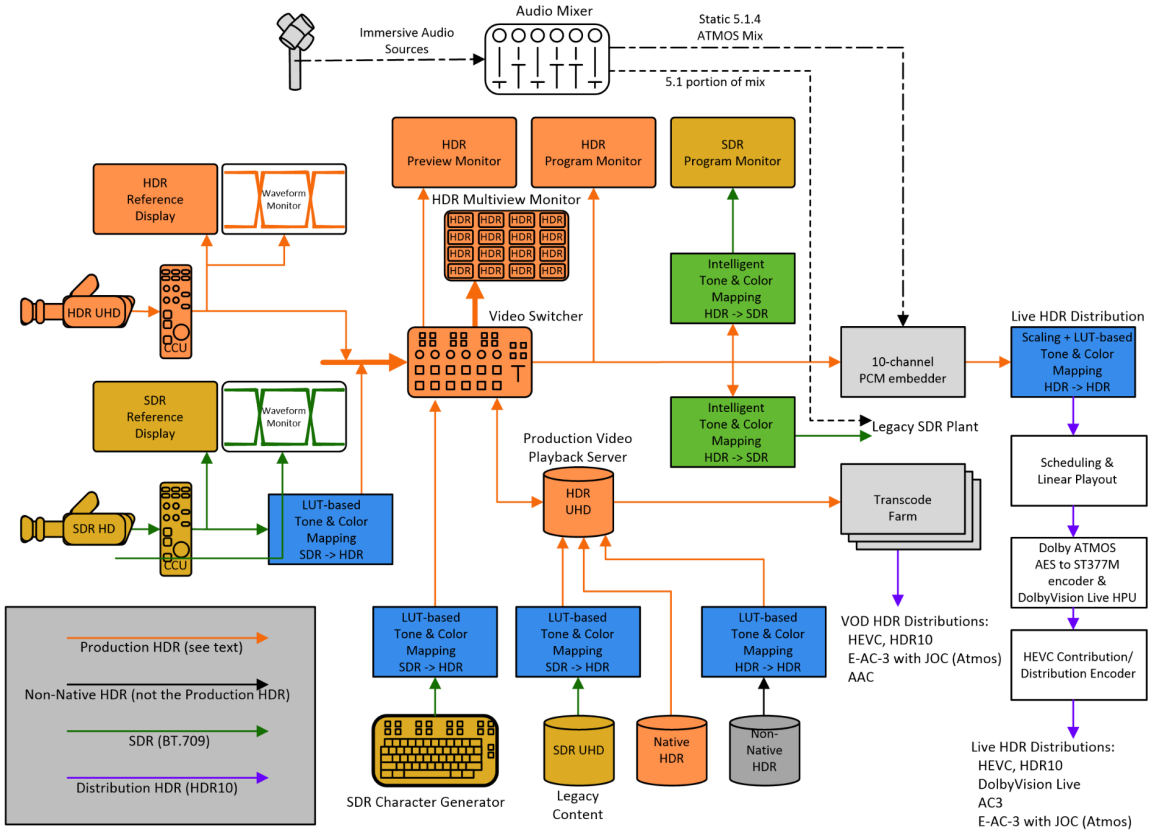

Figure 6. NBCU Olympics and 2018 World Cup UHD Workflow

This workflow includes three different production formats: S-Log3 Live, HLG, and PQ. NBCU chose PQ as a final distribution format, and converted all other formats, including SDR, to this

common production format. The Pyeongchang Olympics were captured in HLG and the World Cup was captured in S-Log3[5] Live.

NBCU has strong preference for PQ as the distribution format, citing that PQ ensures consistency in terms of final delivery that preserves artistic intent and quality. NBCU has found HLG and S-Log3 provides a good basis for conversion to PQ. BT.2020 color is used with PQ.

For shading, NBCU chose a starting point of diffuse white at 200-230 cd/m^{2}and then balances SDR and HDR for the best tonal range.

[5] Sony digital cinema video format,
https://pro.sony/ue_US/technology/s-log
https://www.sony.com/electronics/support/articles/00145908

13.4. Sky UK/BBC Royal Wedding and Major Tennis Tournament

This section describes a workflow used in 2018 that has been superseded. It helped with development of the single-master HDR/SDR workflow that is now in common use, as described in section 7.2 of Report ITU-R BT.2408 [8].

Thanks to Sky UK for providing information to the Ultra HD Forum about their distribution of the Royal Wedding in the UK in 4K resolution, a joint UHD production between Sky UK and the BBC.[6]

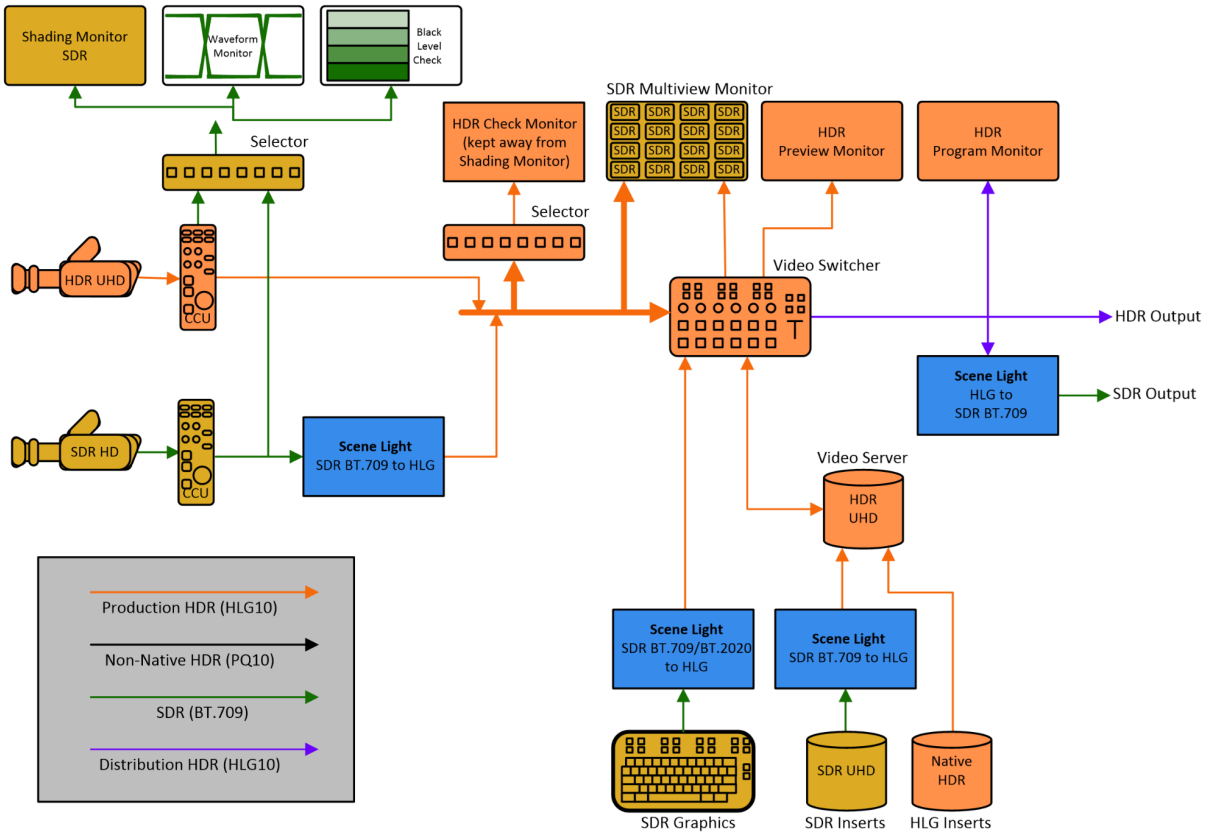

Figure 7. Sky UK/BBC Royal Wedding and Major Tennis Tournament Workflow

[6] See https://news.sky.com/story/world-first-for-sky-news-royal-wedding-coverage-11355412 for additional details.

Although the BBC captured their portion of the content in wide color gamut BT.2100 [5] HLG HDR, the main delivery for this event was HD in SDR/709 [2] with Sky UK distributing UHD SDR/709 in the UK. The use of a single production workflow was necessary and SDR/709 the prime delivery but maintaining the capability to capture the wedding chapel in HDR was a key desire. Sky UK worked with the BBC to convert BT.2100 HLG to SDR/709 for the main Sky UK 4K and HD distribution feed. Numerous tests and trials were conducted in advance to ensure the conversion LUT was working satisfactorily across all colors and luminances. The initial "technically" correct LUTs followed the Macbeth chart closely, but when the color volumes were pushed by adding shiny saturated colored surfaces and glare (using a custom-built test chart), the chroma matching to SDR-matrixed cameras strayed. This had to be addressed due to the highly saturated nature of the fabric of the guards' uniforms and other elements of the event that were expected to challenge the BT.709 capabilities[7].

Sky UK notes that while there were challenges, the event was a good experience and a big step toward having a single live production using both UHD HLG HDR camera outputs and SDR/709 cut seamlessly together delivering both HDR and SDR, UHD and HD.

A similar workflow was adopted by NEP for their Centre Court coverage of the Wimbledon 2018 tennis championships[8] . This time, however, a mixture of HLG HDR and SDR/BT.709 specialist cameras were used. In order to ensure a good color match between HDR and SDR cameras, "scene-light" conversions were utilized and the signal "clippers" on the SDR cameras relaxed to EBU R103 levels (-5%/+105%) to extend their effective color gamut.

[7] See also: https://www.nepgroup.co.uk/post/the-royal-wedding-in-high-dynamic-range and https://www.bbc.co.uk/rd/blog/2018-05-ultra-high-definition-dynamic-range-royal-wedding-uhd-hdr

[8] See also: https://www.nepgroup.co.uk/post/live-from-wimbledon-host-broadcaster-pacing-like-an-expectant-father-as-coverage-goes-in-house-for-the-first-time

13.5. BBC 2019 Football Association Challenge Cup

The BBC's 2018 live UHD HDR productions used parallel UHD HDR and HD SDR workflows, to minimize the risk of compromising the picture quality for HD SDR viewers. However, their joint coverage of the 2018 Royal Wedding with Sky UK(see Section 13.4.) proved that format conversion technology had matured sufficiently to allow a high quality SDR signal to be derived from a single HLG HDR production workflow, greatly simplifying the production and reducing costs.

So, for the BBC's coverage of the FA Cup quarter finals, semi-finals and final, the BBC adopted a single UHD HLG HDR workflow to feed both their domestic UHD HDR and HD SDR distribution, as well as to provide UHD and HD SDR signals to other rights holders. The simplified production architecture is illustrated in Figure 8.

Football is one of the most technically challenging sports to produce, making extensive use of specialist cameras and sophisticated graphics for ball-tracking and AR (augmented reality). The complexity of the BBC's production increased through each round of the tournament. By the time of the final the BBC's coverage was spread across two OB trucks controlling 41 cameras. It included six super-slo mo cameras, four RF cameras, a Spidercam, a helicopter camera (helicam), polecams and robotic cameras (robocams). One truck provided the match coverage, and the other "presentation" truck provided the BBC's domestic output, which included a local presentation studio.

The native displayed color of objects within a scene is different for each production format as they utilize different end-to-end opto-optical transfer functions (OOTFs) and color primaries. So, with such a complex mix of sources, it is important to use the correct type of HDR/SDR format conversion to achieve a good color match:

"Scene-light" conversions based on the light falling on a camera sensor, should be used for matching camera sources. They are calculated using cameras OETFs and their inverse.

"Display-light" conversions based on the light reproduced by a reference display, should be used for graphics and graded content. They are calculated using display EOTFs and their inverse.

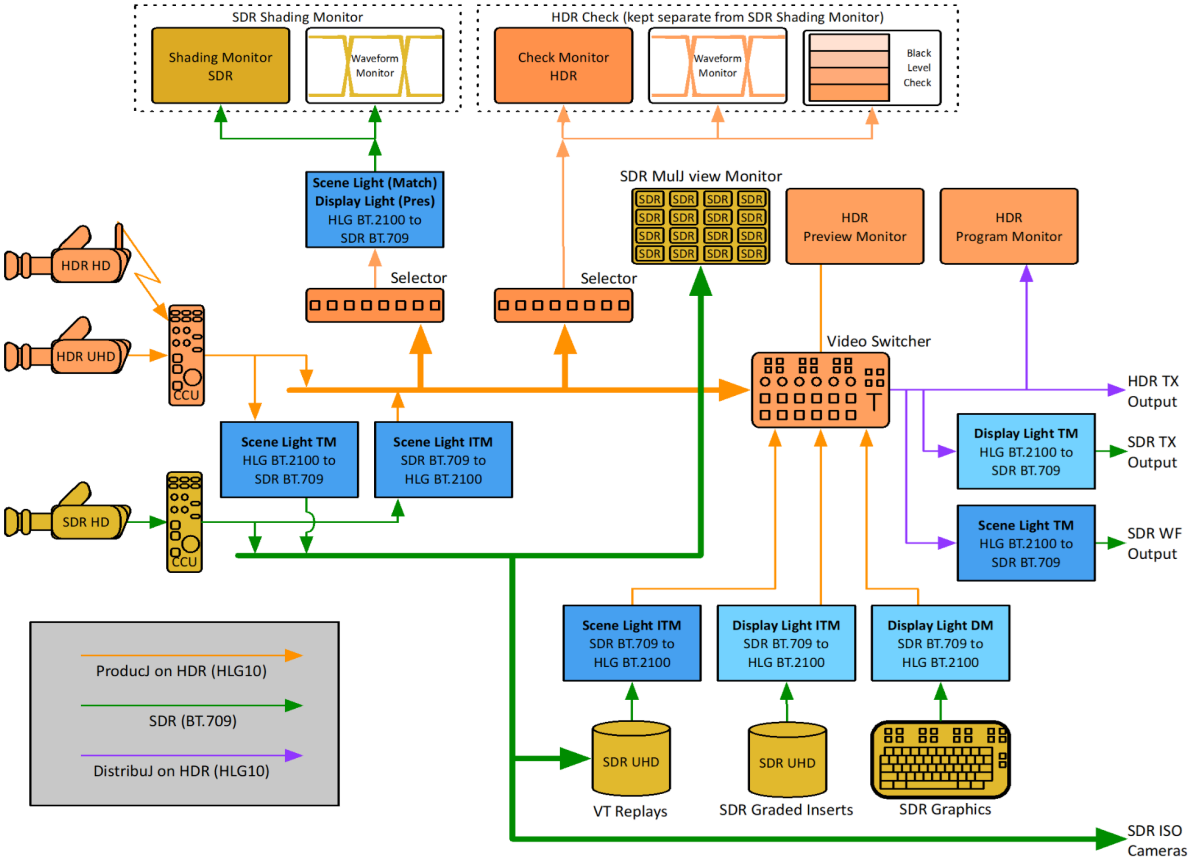

Figure 8. BBC 2019 Football Association Challenge Cup Workflow

More details of the recommended conversions for different signal sources can be found in the ITU report BT.2408 "Guidance for operational practices in HDR television production" [8].

Whilst the main cameras (including RF and helicam) were operating in HLG HDR, the super-slomo and specialist cameras could only operate in SDR BT.709. So "scene-light" conversions were used to convert the SDR camera outputs to HLG HDR, thereby providing a good color match with native HLG HDR cameras. A small "boost" was applied to the SDR camera highlights (known as inverse tone mapping (ITM) or "up-mapping") to better match the appearance of the native HDR cameras.

The “VT” area (record/edit/playback) providing action replays and pre-prepared program inserts, was also limited to 8-bit SDR, and every single camera was made available to other broadcasters in SDR (shown as SDR ISO feeds in Figure 8). So a “scene-light” conversion was used to convert the HLG HDR camera outputs to SDR BT.709, thereby providing a signal with a good color match to the native SDR cameras covering the event. Highlights from the HDR cameras were compressed using a “knee” type function (known as tone mapping (TM) or “down-mapping”) as part of the conversion to SDR. This not only improved the SDR picture quality, but reduced the “round-trip” losses when converting back to HDR for re-insertion into the program on the “VT” output.

In addition to the UHD HDR output, the BBC provided two different SDR program feeds:

- a “clean” (i.e. without graphics) “World-Feed” as a scene-light conversion from HLG to BT.709, to match the camera ISO feeds (SDR) and the SDR cameras of other broadcasters;
- a “dirty” (i.e. with graphics) BBC transmission output as a display-light conversion from HLG to BT.709, thereby ensuring identical colored graphics in the BBC’s HDR and SDR programs.

To ensure the highest quality SDR output, the cameras were shaded using an SDR monitor, fed from the HLG signals using the same converters that provided the SDR program outputs. For operational reasons, cameras shaded in the “match” truck used the same scene-light conversion as the SDR “World Feed”. Cameras shaded in the “presentation” truck used the same display-light conversion as the BBC’s SDR transmission feed. In theory either could have been used. They differed slightly in terms of color saturation and shadow detail, but were both within the usual artistic tolerances for SDR football.

Program graphics were generated in SDR and converted to HLG using a display-light “direct mapping” conversion i.e. without boosting of highlights. The display-light conversion ensured that the graphics colors were maintained across both BBC outputs, and matched those of a conventional SDR production.

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[O] **Orange Boo**k – Foundational Technologies for Ultra HD

[OR01] Section 7, Foundational Technologies for Ultra HD

[Y] **Yellow Book** – Beyond Foundational Technologies

[Y01] Section 7.1, HDR w/Dynamic Metadata

[Y02] Section 7.1.3, Dual Layer (SL-HDR 1 and SL-HDR 2)

[G] **Green Book** – UHD Distribution

[G01] Table 11, STB HDR/SDR Modes

[B] **Blue Book** - Ultra HD Production and Post Production

[B01] Section 7.2, Static HDR Metadata-SMPTE ST 2086, MaxFALL, MaxCLL

[B02] Section 8, Conversions Between Transfer Functions

[I] **Indigo Book** – Ultra HD Technology Implementations

[I01] Section 12.2.4,Timeline for TV 3.0

(End of Violet Book)