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Digital Video Subcommittee

SCTE INDUSTRY REFERENCE

SCTE 247 2018 (R2024)r1

High Dynamic Range (HDR) Video: System Requirements for Cable Phase 1- Initial Deployment

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140 Philips Road
Exton, PA 19341

Document Tags

☐ Specification	☐ Checklist	☐ Facility
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Note: This document is a reaffirmation of SCTE 247 2018. No substantive changes have been made to this document. Information components may have been updated such as the title page, NOTICE text, headers, and footers.

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1. Introduction

1.1. Executive Summary

Note: This document is a reaffirmation of SCTE 247 2018. No substantive changes have been made to this document. Information components may have been updated such as the title page, NOTICE text, headers, and footers.

This SCTE document on High Dynamic Range (HDR) Video: System Requirements for Cable Phase 1- Initial Deployment was created in 2018 and represents a snapshot of the requirements in 2018. Since then, HDR technology has matured beyond initial deployment and new formats are in use in the general industry. Systems requirements would likely expand in the future to include remapping and conversions to other HDR and dynamic metadata formats (such as, for example, those stated in post 2018 revisions of SCTE 215-1). These additional requirements might be addressed in future versions of this document.

The consensus of the drafting group members is that HDR10 is appropriate for use in the cable industry for a "first pass" HDR video distribution option against the time constraints larger operators desire to meet. Other existing HDR formats used for content or advertising production have appropriately defined conversion methods that allow other options to be used but translated for cable distribution. HDR10 is used by both Blu-ray and Internet streaming providers, which ensures the availability of high-quality content in the format and the availability of technical systems products that will meet the needs of the cable industry. HDR10 processing and display is supported across the widest variety of currently available and next-generation television, computer, tablet, and phone devices. Its performance many be improved in the future with the optional inclusion of dynamic metadata, as the ability to create and deliver it becomes a practical possibility in the content production and distribution ecosystem. SCTE should proceed expeditiously to document HDR10 for cable systems to address initial industry launch demands while continuing work to consider other HDR options for use in cable where appropriate. The HLG HDR system, which operates simply without HDR metadata of any kind to complicate the various cable system workflow and processing systems, is also a potentially valid solution to some of the issues identified in this document, and should be evaluated along with other HDR systems and metadata based enhancements to HDR10 in future phases of HDR standardization.

A non-consensus opinion is noted in section 9.3.

1.2. Background

From origins using an 'amplified pipe' for the distribution of off-air television signals, the cable industry has successfully adopted, evolved and innovated distribution technologies used to provide information and entertainment services to consumers. Like the change from analog to digital audio and video formats, the nature of cable technology has been to *embrace* potentially disruptive and different technologies – but deploy those technologies to consumers in what is actually a more measured *evolution*.

Next-generation video services and related consumer product offerings are disruptive and quite varied in their technical nature. In the context of this document -- and requirements within -- the reader should use care to understand the context of the advanced services – high dynamic range (HDR) video services are potentially only one component of a next-generation consumer offering, perhaps combined with wide color gamut (WCG), and possibly higher-resolution ultra-high definition video (UHD) and higher frame rate (HFR) video.

The objective of this requirements document is to define the technical elements of next-generation video systems that are necessary for the cable industry. These technical details will enable proponents and designers to specify a system necessary to support a product offering that can be standardized and deployed via cable systems to consumers.

Use of the singular 'system' in the preceding paragraph is further detailed in the document – additional features and evolution of next-generation technologies *may* occur over time, however, the intent of this document is to provide a narrow and succinct choice of parameters that will enable an initial launch to consumers with a stable platform and provide future-proof evolutionary paths toward enhancements. Generally, and colloquially, that evolution could be referred to as 'crawl, walk, run.'

1.3. Scope

This document represents a collaborative collection of use cases and requirements that the SCTE•ISBE Digital Video Subcommittee (DVS) members believe will be a first step for a comprehensive set of Standards, Recommended Practices and other documents that define a next-generation system of high dynamic range video for cable operators.

It is important to note that next-generation video and audio systems are part of an entire ecosystem from capture to production through distribution to consumer consumption. There are several trade organizations and standards development organizations (SDO) that are actively working on, and have oversight over, aspects of those technical details. Notably:

- High dynamic range video system parameters for production have been developed internationally and are documented in ITU-R Recommendation BT.2100 "Image parameter values for high dynamic range television for use in production and international programme exchange." Two different high dynamic range systems are included: a display-referred perceptual quantization (PQ) system and a scene-referred hybrid log gamma (HLG) system. ,
- The next-generation ATSC 3.0 terrestrial broadcast standard [4] allows multiple HDR Video representations [ref A/341].
- The parameters for delivery of HDR video across the uncompressed consumer electronics interface are specified in CTA 861-G. [29].

The use of these standards by cable operators' ecosystem partners necessitates considerations about interoperability and technical interfaces among content creators, programmers, broadcasters and cable operators of varying size and technical infrastructure. Cable content *shall* interoperate smoothly with consumer electronics devices. These format discussions have both technical and business ramifications. This document does not intend to codify those specifications. However, for clarity and information, those ecosystem components *may* be described herein.

1.4. Benefits

Generally, these requirements are in tabular form. The requirements describe the functional and technical needs for the successful design and selection of a next-generation video system.

1.5. Intended Audience

This document is intended for system proponents, design and development engineers as well as cable operators. Product feature and, potentially, marketing groups may use this document to ensure overall needs are addressed.

1.6. Areas for Further Investigation or to be Added in Future Versions

This requirements document, while initially static, tries to take a snapshot of a dynamic area of technology. Next-generation technologies described herein will lead to standards, specifications and/or recommended practices for an end-to-end cable infrastructure. They will determine interfaces and points of interconnect with other system elements such as program providers and consumer electronic devices used by consumers – some or all of which may evolve over time.

2. Normative References

The following documents contain provisions which, through reference in this text, constitute provisions of this document. The editions indicated were valid at the time of subcommittee approval. All documents are subject to revision and, while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

No normative references are applicable.

2.2. Standards from Other Organizations

No normative references are applicable.

2.3. Other Published Materials

No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

[1] ANSI/SCTE 215-1 2015, HEVC Coding Constraints for Cable Television Part 1- Coding [HDR UPDATE IN PROCESS]

[2] ANSI/SCTE 215-2 2015, HEVC Video Constraints for Cable Television Part 2- Transport [HDR UPDATE IN PROCESS]

[3] ANSI/SCTE 172 2017, Constraints On AVC and HEVC Structured Video Coding for Digital Program Insertion.

3.2. Standards from Other Organizations

[4] SMPTE ST 2086:2014: Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images.

[5] ITU-R BT.2100-1:2017 Image parameter values for high dynamic range television for use in production and international programme exchange.

[6] ITU: Report ITU-R BT.2390, "High dynamic range television for production and international programme exchange," International Telecommunications Union, Geneva.

[7] ATSC: "ATSC 3.0 System" (A/300)," Doc. A/200:2017, Advanced Television Systems Committee, Washington, D.C., 19 October, 2017

[8] IEEE: "Use of the International Systems of Units (SI): The Modern Metric System," Doc. SI 10, Institute of Electrical and Electronics Engineers, New York, N.Y.

[9] ISO/IEC: "Information technology – High efficiency coding and media delivery in heterogeneous environments – Part 2: High efficiency video coding," Doc. ISO/IEC 23008-2:20151. Note that this version of the HEVC specification does not include all items referenced by this document. JCTVC-Y1003, which is available at http://phenix.intevry.fr/jct/doc_end_user/documents/25_Chengdu/wg11/JCTVC-Y1003-v1.zip defines these additional items.

[10] ITU: ITU-R Recommendation BT.601-6 (2007), "Encoding Parameters of Digital Television for Studios," International Telecommunications Union, Geneva.

[11] ITU: ITU-R Recommendation BT.709-5 (2002), "Parameter values for the HDTV standards for production and international programme exchange," International Telecommunications Union, Geneva.

[12] ITU: ITU-R Recommendation BT.2020-1 (2014), "Parameter values for ultra-high definition television systems for production and international programme exchange," International Telecommunications Union, Geneva.

[13] SMPTE: "Format for Active Format Description and Bar Data," Doc. SMPTE ST 2016-1 (2009), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[14] SCTE: "AVC Video Constraints for Cable Television, Part 1 – Coding," Doc. ANSI/SCTE 128-1 2013, Society of Cable Telecommunications Engineers, Exton, PA.

[15] CTA: "Digital Television (DTV) Closed Captioning," Doc. ANSI/CTA-708-E, Consumer Technology Association, Arlington, VA, August 2013.

[16] SMPTE: "Electro-Optical Transfer Function for High Dynamic Range Reference Display" Doc: ST 2084 (2014), Society of Motion Picture and Television Engineers, White Plains, NY.

[17] ATSC: "ATSC Proposed Standard: Signaling, Delivery, Synchronization, and Error Protection (A/331)," Doc. S33-174r6, Advanced Television Systems Committee, Washington, D.C., 4 May 2017. (work in process)

[18] SMPTE: "Ultra High Definition Television — Image Parameter Values for Program Production," Doc. SMPTE ST 2036-1 (2013), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[19] SMPTE: "Standard for Television—1920 x 1080 Scanning and Analog and Parallel Digital Interfaces for Multiple Picture Rates," Doc. SMPTE ST 274 (2008), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[20] SMPTE: "Standard for Television—1280 x 720 Progressive Image Sample Structure, Analog and Digital Representation and Analog Interface," Doc. SMPTE ST 296 (2012), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[21] SMPTE: “SDTV Component Video Signal Coding 4:4:4 and 4:2:2, for 13.5 MHz and 18 MHz Systems,” Doc. SMPTE ST 125 (2013), Society of Motion Picture and Television Engineers, White Plains, N.Y

[22] SMPTE: “Standard for Television—3 Gb/s SDI Signal/Data Serial Interface,” Doc. SMPTE ST 424 (2012), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[23] SMPTE: “Standard for Television— Professional Media Over Managed IP Networks” Doc. Suite SMPTE ST 2110-x (2017), Society of Motion Picture and Television Engineers, White Plains, N.Y.

[24] ETSI: “Digital Video Broadcasting (DVB); Specification for the use of Video and Audio Coding in Broadcasting Applications based on the MPEG-2 Transport Stream,” Doc. ETSI TS 101 154 V2.1.1 (2015-03), European Telecommunications Standards Institute, Sophia Antipolis Cedex – FRANCE.

[25] CTA: “Active Format Description (AFD) and Bar Data Recommended Practice,” Doc. CTA-CEB16-A, Consumer Technology Association, Arlington, VA, July 2012.

[26] DTG: “Digital Receiver Implementation Guidelines and Recommended Receiver Reaction to Aspect Ratio Signaling in Digital Video Broadcasting, v2.0.0”, January 2012. Digital TV Group, London, England.

[27] ATSC: “Video - HEVC” Doc. A/341:2017, Advanced Television Systems Committee, Washington, D.C., 19 May 2017. (and associated amendments)

[28] ATSC: “Audio Common Elements,” Doc. A/342 Part 1:2017, Advanced Television Systems Committee, Washington, D.C., 24 January 2017.

[29] CTA: “A DTV Profile for Uncompressed High Speed Digital Interfaces,” Doc. ANSI/CTA-861-G, Consumer Technology Association, Arlington, VA, November 2016.

[30] ISO/IEC 13818-1, (2013), “Information Technology—Generic coding of moving pictures and associated audio—Part1: Systems.

3.3. Other Published Materials

[31] ITU: Report ITU-R BT.2408-2017 “Operational Practices in HDR Television Production," International Telecommunications Union, Geneva Compliance Notation

[32] UltraHD Forum "UltraHD Forum: Phase A Guidelines Rev. 1.4", Aug 25, 2017, Fremont, CA.

4. Compliance Notation

shall	This word or the adjective "***required***" means that the item is an absolute requirement of this document.
shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified ***shall*** never be used.
should	This word or the adjective "*recommended*" means that there *may* exist valid reasons in particular circumstances to ignore this item, but the full implications *should* be understood and the case carefully weighed before choosing a different course.
should not	This phrase means that there *may* exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications *should* be understood and the case carefully weighed before implementing any behavior described with this label.
may	This word or the adjective "*optional*" indicate a course of action permissible within the limits of the document.
deprecated	Use is permissible for legacy purposes only. Deprecated features *may* be removed from future versions of this document. Implementations *should* avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

4G	Generally, advanced commercial mobile radio services (licensed wireless carriers)
ATSC	Advanced Television Systems Committee
CEA / CTA	Consumer Technology Association
COAM	customer owned and managed (e.g. not supplied by the cable provider)
DASH	dynamic adaptive streaming over HTTP
DOCSIS	Data Over Cable Service Interface Specification, used herein as a generic reference to current cable modem service
DVR	digital video recorder; also cDVR (cloud-based DVR)
DVS	SCTE•ISBE Digital Video Subcommittee
EOTF	electro-optical transfer function
HD	high definition; generally 1920x1080 or 1280x720
HDCP	High-Bandwidth Digital Content Protection
HDMI	high definition multimedia interface
HDR	High-dynamic range (generic reference, document context is important); generally ITU definition.[5]
HFC	hybrid fiber-coax
HLG	hybrid log gamma
HLS	HTTP live streaming
IP	Internet protocol
ISBE	International Society of Broadband Experts
QAM	quadrature amplitude modulation, generically a cable method of carriage of MPEG transport to consumers; typically implies linear program streams
SCTE	Society of Cable Telecommunications Engineers

SD	standard definition; generally 480i
SDO	standards development organization
STB	set top box; generic reference to a standalone, multifunction content processing and rendering device
UHD	ultra-high definition (generally, 3840x2160 16:9 raster geometry)
WCG	wide color gamut; generally, color space greater than [10][11]
Wi-Fi	Generally, unlicensed wireless IP connectivity (Wi-Fi Alliance)

5.2. Definitions

Definitions of terms used in this document are provided in this section. Defined terms that have specific meanings are capitalized. When the capitalized term is used in this document, the term has the specific meaning as defined in this section.

Slate	A static, consumer-informative graphic providing information such as blackout status.
TV Everywhere	Generally, a broadband content service delivered via broadband to subscribers of a cable provider.

6. Introduction to High Dynamic Range Video

6.1. Video System Discussion

As noted in the Background section of this document, the end-to-end nature of video services necessitates that some latitude be afforded to the description of how this SCTE document fits within the scope of other SDO work.

High dynamic range video *shall* be considered in the context of modern cable systems, in which cable operators deliver a variety of video services (e.g., live linear channels and on-demand content) to a variety of consumer devices (e.g., cable STBs, smart TVs, PCs, tablets and smart phones) over different network infrastructures (e.g., the cable hybrid fiber-coax (HFC) plant, in-home DOCSIS/WiFi IP delivery and external internet connections such as wireless carriers' 4G networks). In addition, DVR, "cloud DVR" and "start-over viewing" add complexity and technical requirements to the not-so-simple case of live linear channels.

The result is that modern cable systems must support many different, highly complex paths in which content must flow among various subsystems with cable operators' plant. Moreover, cable operators exist in the middle of an entire end-to-end ecosystem in which many aspects of content production and consumer devices are beyond their control, but which impose certain technology constraints and limitations. In order to develop the requirements contained in this document, SCTE DVS scrutinized both live linear channels and on-demand content delivery on an end-to-end basis – from content production through various stages of delivery all the way to the consumer display. It is clear that the requirements for Next-generation cable systems need to take into account many important complexities and differences from the far simpler situation of purely on-demand delivery of pre-recorded content; and yet next-generation cable systems must provide a competitive viewing experience.

Figure 1 provides a very simplified high-level view of the end-to-end content ecosystem for the case of live linear channels. The Figure is intended to provide a high-level reference for discussing the functionality that is required throughout the content ecosystem; it is not representative of specific systems

or architectures, which can vary widely among various content producers, programmers and cable operators.

Referring to Figure 1, on the 'production' side of content, it is important to understand that there are two categories of linear content creation and distribution – truly "live television" streams, which may include sports, special events, news and other content, and linear streams which are a compilation of pre-recorded content (a traditional linear television channel).

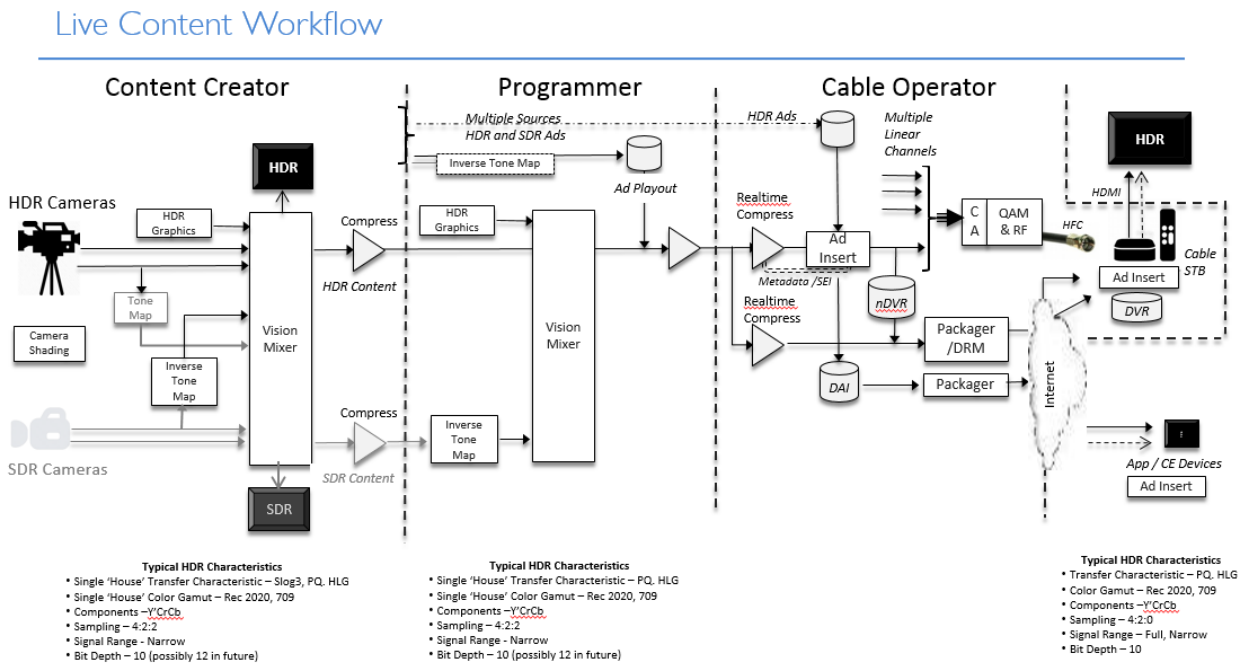

Figure 1 - Live/Linear Content High-Level Ecosystem View

The linear television signals that cable operators deliver to their subscribers comes from many sources, including cable programmers, broadcast network local TV station affiliates and independent local broadcast TV stations, and operator-produced programming such as sports and news. In particular, the production of live television programming has many considerations related to producing content for both next-generation distribution and audiences as well as legacy HD and SD distribution and audiences. Although the topic is outside of SCTE's scope, some of the many production considerations regarding proper camera shading, lighting, conversion between PQ and HLG HDR systems, the SDR to HDR upconversion and HDR to SDR downconversion needed to intermix HDR and SDR cameras, and graphics generation for both signals are described in ITU-R Report BT.2408-2017 "Operational Practices in HDR Television Production" [31], and the "UltraHD Forum Phase A Guidelines" [32].

Subject to change over time, Figure 2 shows a more detailed view of the many different conversion steps that are encountered between a camera and the distribution compression encoder, which is presumed to be HEVC Main 10 [[9],[1],[2]]. Live television cameras transform the high dynamic range linear light red, green and blue signals into a non-linear transfer characteristic luminance signal and subsampled color difference signal representation, typically Y'CrCb (or, possibly, ICtCp) signals with a 10-bit codeword space (although more bits may be used in the future) [6]. This signal representation is the basis for subsequent signal interfaces in programmer playout and ad insertion systems and for linear signal distribution to cable operators. The details of these HDR signal representations are described in ITU-R Recommendation BT.2100 "Image parameter values for high dynamic range television for use in

production and international programme exchange" [6] and ITU-R Report BT.2390 "High dynamic range television for production and international programme exchange [31]. It is a notable constraint that the current live signal interfaces and equipment that are in widespread for live/linear television production [22], [23] use do not support synchronous delivery of optional dynamic metadata that may be associated with some HDR video signals. While the advent of IP-based systems for professional television production [23] has the potential to provide such capabilities in the future, the widespread adoption and deployment of IP based systems will take considerable time. The "UltraHD Forum Phase A Guidelines" [32] also discusses many of the practical aspects of HDR systems and conversions among them.

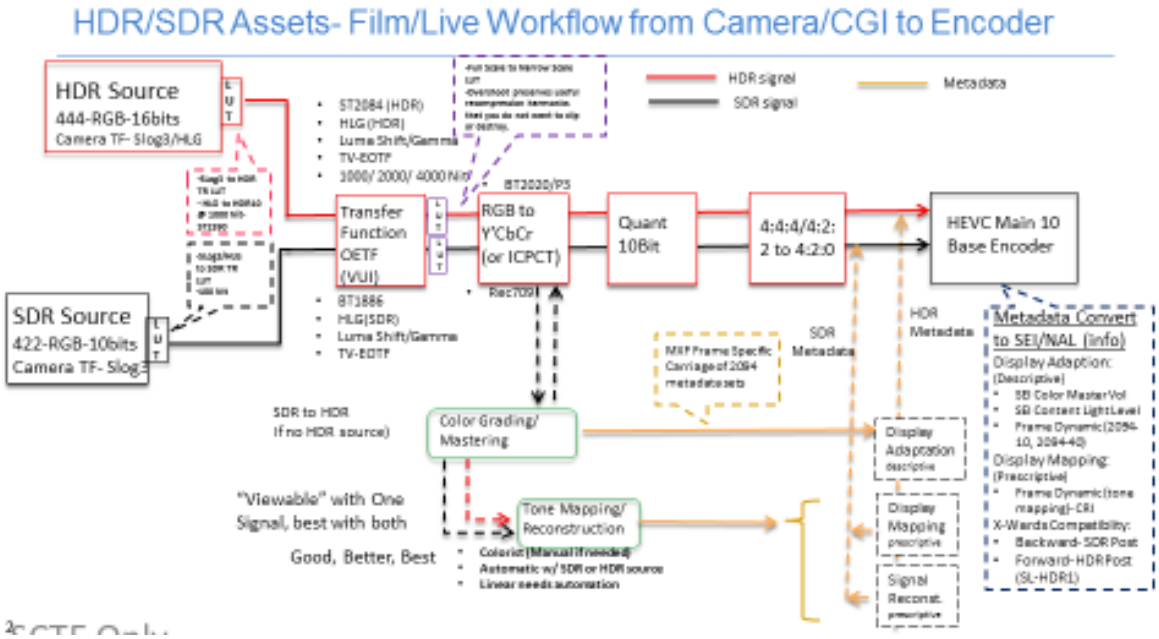

Figure 2 - Conceptual Production Workflow Source to Encoder

Referring again to Figure 1, as a live production signal is fed to a cable programmer, advertisements are inserted at appropriate points during the event. This is accomplished by ad playout servers and the same live signal interfaces [19] [20] that are used in production. To avoid consumer dissatisfaction and operational complexity, current operational practice is constrained to require that the ad inventory use the identical video format to the live production. Programmers may also insert graphics elements "downstream" from the actual production, often including channel branding logos and promotional animated graphic elements. Programmers then distribute their fully integrated linear signal to cable operators and other distributors, often applying video compression during this step. The limitations that are encountered in the delivery of content to cable operators impose important practical constraints on the end-to-end approaches that are suitable for next-generation video and audio systems for cable.

Cable operators receive linear channel feeds from many different programmers. In addition, cable operators re-transmit local TV broadcast stations. In many larger markets, a direct fiber connection is available between TV stations and cable ingest points. However, many markets continue to rely on direct reception of broadcasters' over-the-air signals as the source for re-transmission.

In addition to live linear transmission, cable operators provide DVR, "cloud DVR" and "start-over viewing" functionality to subscribers. Modern cable systems and TV Everywhere services require the delivery of recorded content to different classes of STBs and consumer devices. In order to minimize picture quality loss, complexity and latency, careful attention should be given to the relationship between

linear transmission formats and the storage formats that are required to fulfill DVR and "start-over" services.

Cable operators also have a significant business in ad insertion for both programmer and broadcast channels, since they can perform geographically and/or demographically targeted ad insertion. Advertising segments used by cable operators come from a wide variety of national and local sources. Cable operators' ad insertion systems and ad inventories must deal with the variety of source signals and video formats (e.g., HD 1080i [19], HD 720p [20], SD [21]) that are distributed by various programmers and broadcasters. Moreover, cable operators must be able to insert advertising in linear channels, "start-over" playback, DVR playback, and on-demand viewing. The technical quality, complexity and latency *shall* meet both operational and business agreement needs.

In particular, content owners, programmers and advertisers are usually very concerned that the "creative intent" of their content be fully preserved by cable operators' delivery to consumer displays. For example, UHD Alliance technical specifications associated with the "UltraHD Premium" logo require content, delivery and display using the ST-2084 PQ EOTF. Thus, while many format conversions can be performed technically, they may be prohibited or limited in certain ways by business agreements and the attempt to use a plethora of options may delay the timely roll out of HDR to consumers. Conversions that may be required among various HDR video systems are complex and their potential consequences drive many of the requirements in this document. This is more than just a consequence of content agreements. Simplifying operational complexity in the system is necessary to deploy HDR services in a timely manner and at scale, with the same expected customer experience (or better). The adoption of multiple formats affects the implementation scale in terms of transmission and storage (including ads). Likewise, multiple HDR implementations will complicate the insertion of ads and other existing and revenue-producing functions. In the spirit of crawl/walk/run, it is recommended that this document recommend only one electro-optical transfer function (EOTF) and one color space with limited metadata options for initial (phase 1) deployment.

Finally, the networks used and the consumer devices to which cable operators deliver their services vary widely in their capabilities and interfaces. A typical situation from encoder to decoder is shown in Figure 3.

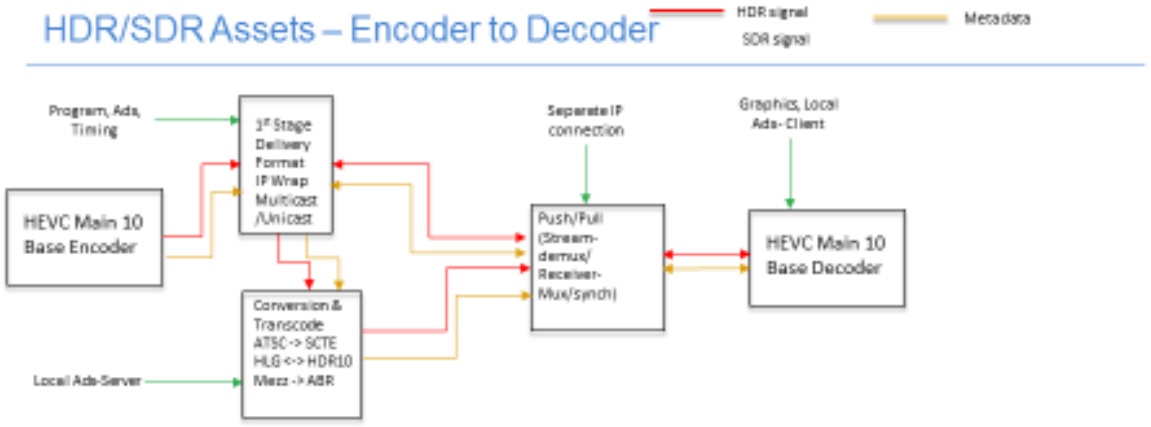

Figure 3 - Encoder to Decoder with Ad Insertion

In the case of delivery to a cable operator controlled set top box (STB), video compression at the headend and decompression in the STB are controlled by the cable operator, as are the insertion of navigational and closed caption graphics. The consistency and visual quality of navigation functions (e.g., picture-in-

picture, multi-channel mosaic screens, etc.) and graphics across various programming channels are important requirements for providing a high quality user interface and navigation experience to subscribers. In addition, as shown in Figure 3, ad insertion may be performed "on the client side" of the operators' network, either in the set top box or in a consumer device that is running a TV Everywhere software application.

Cable STBs connect to modern TVs with the HDMI interface, as shown in Figure 4. (Although analog interfaces still exist in legacy STBs and old TVs, only HDMI with content protection such as HDCP is relevant to next-generation video and audio).

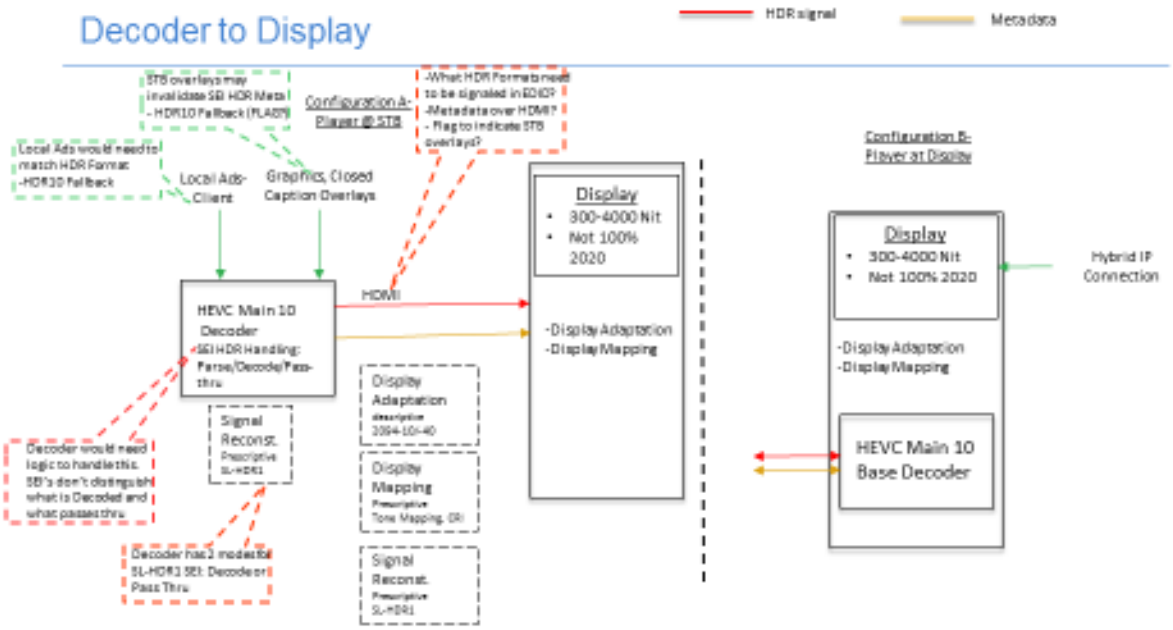

Figure 4 - Decoder to Display

The video format of an HDMI connection is determined by a special initialization "handshake", during which no video data is transferred. Switching from one HDR format to another may cause an HDMI format switch. The viewer disruption associated with an HDMI format switch has resulted in current practice being to have the STB output a single video format to the TV. Avoiding the disruptive experience associated with an HDMI format switch is another important requirement and consideration for HDR video. As client-side advertising, graphic overlays and other similar 'manipulation' may be done, the decoder to display functionality is also shown in more detail in Figure 4.

Both in-home and out of home (TV Everywhere) content delivery over the internet directly to consumer devices use a different approach than delivery to a set top box, where the operator's application on the device is able to negotiate the delivery of a streaming format that is appropriate to the capabilities of the device. Ad insertion must also be performed with internet delivery and both server-side and client-side insertion *shall* be accommodated. Adaptive bit rate (ABR) streaming facilitates simple changes in video resolution as network conditions change; but the limitations of current devices generally do not allow on-the-fly switching among various HDR systems. Cable operators' *shall* provide subscribers with a consistent user interface and navigation system regardless of whether the client device is a fully integrated decoder/display device running an app or an operator-provided STB connected to a display using an HDMI interface. The practical limitations of client-side ad insertion, graphic overlays for user interface

and navigation and undesirable effects associated with switching formats across an HDMI connection are all important considerations in the requirements for HDR video in cable systems.

Figure 5 provides a high-level view of the end-to-end content ecosystem for the case of scripted content and on-demand delivery.

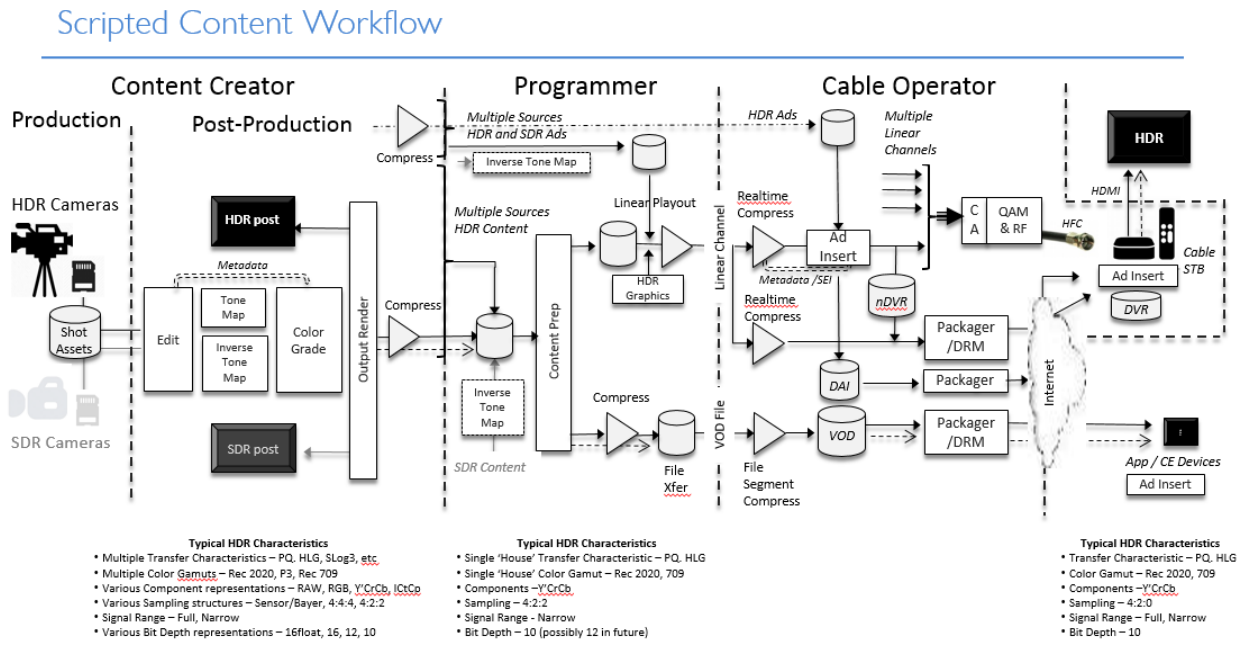

Figure 5 - Scripted Content and On-Demand High-Level Ecosystem View

The on-demand content that cable operators deliver to their subscribers comes from many sources, including movie studios, cable programmers, broadcast networks, local TV stations and operator-produced content. Produced and distributed individually as programs, different production, post-production and finishing techniques are used. This workflow is exemplified by scripted programming (shows, movies, etc.) and Figure 6 shows many of the video format conversion steps that take place in typical file-based asset workflows.

While careful color grading can be performed and related HDR dynamic metadata can be created during content production, it is not assured that such metadata will be transported in the distribution file formats provided to cable operators.

During the path from creation through distribution many processing steps are undertaken such as encoding, distribution conforming, advertising insertion or other forms of switching and integration, depicted in Figure 5.

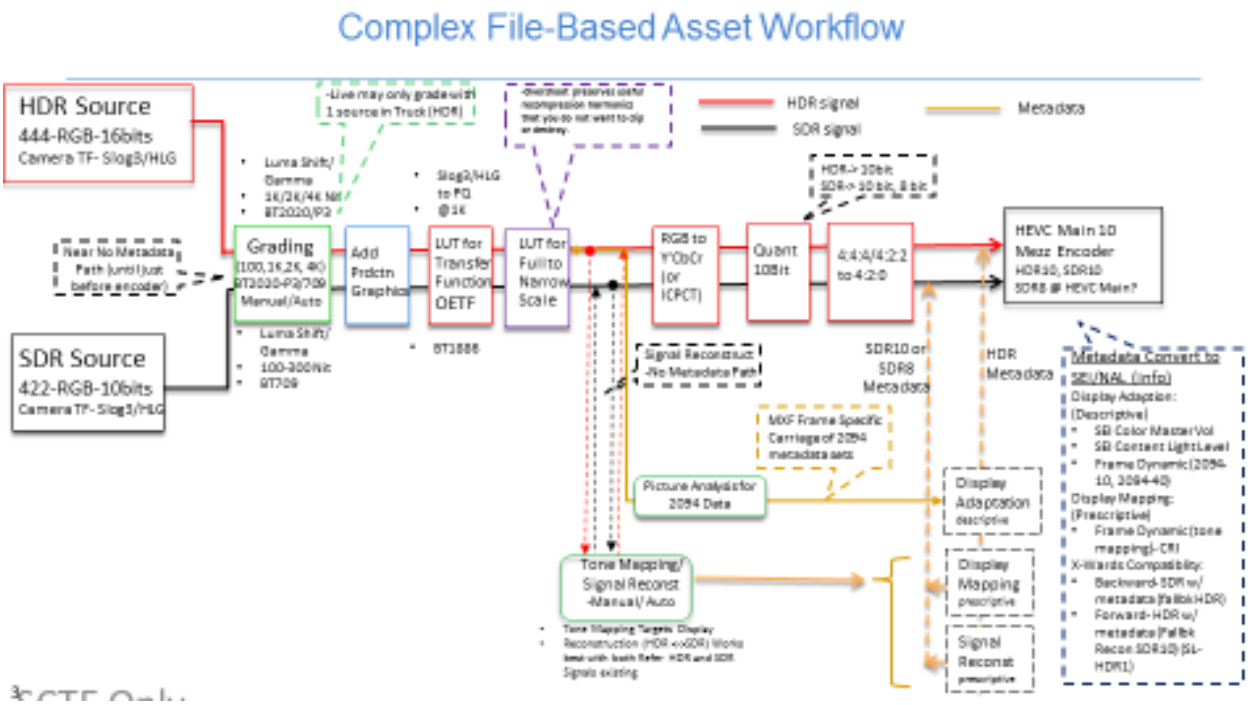

Figure 6 - Complex File-Based Asset Workflow

The digital files delivered to cable operators are transcoded by cable operators to the specific formats required by their cable on-demand and internet on-demand systems. It is not assured that dynamic metadata will be preserved through various transcode operations. Further, internet on-demand servers are often used in conjunction with "packagers" that format the compressed video streams into the IP transport requirements of the requesting device (e.g., HLS, DASH or other streaming formats).

In addition, many on-demand services require the insertion of advertising segments, which similarly come from a wide variety of sources. These on-demand systems and the insertion of advertising require that the same video format is maintained across the content and the ad.

The limitations that are encountered in the delivery of content to cable operators is an important practical constraint on the end-to-end approaches that are suitable for next-generation video and audio systems for cable.

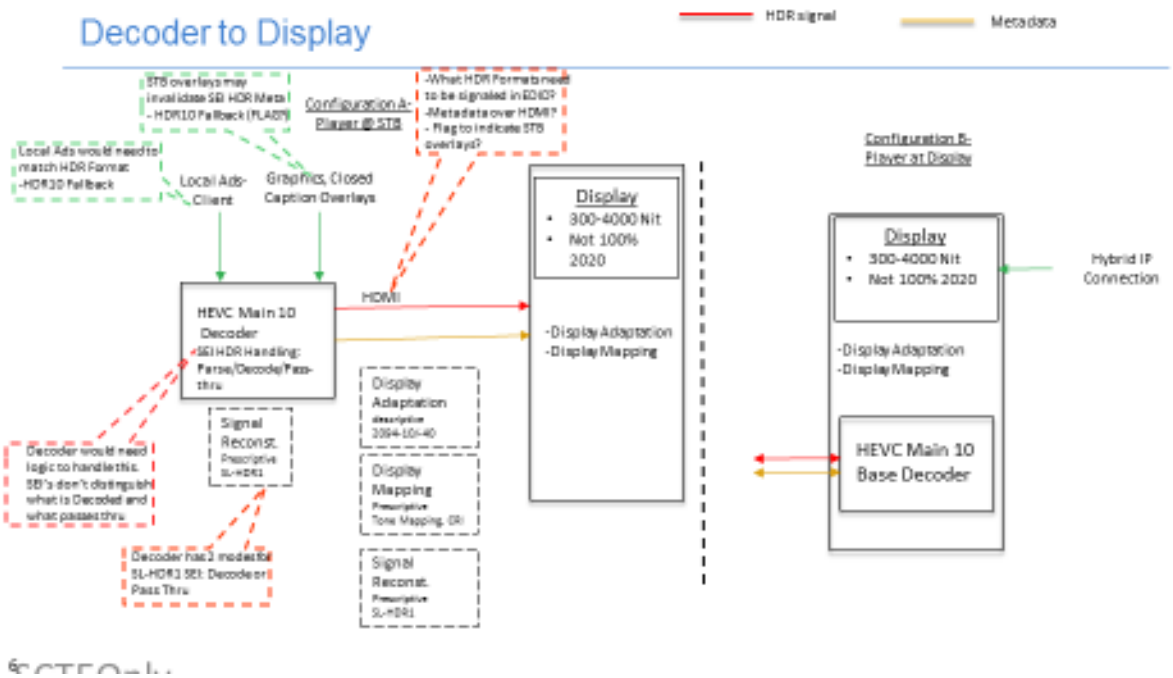

Figure 7 - Decoder to Display

6.2. Description of Systems In Use Today

For HDR content delivery systems, many more options exist [ref UHDF], which have been created with different design goals in mind. Among these are:

HDR10 Media Profile (or just HDR 10) is a CTA combination of the PQ EOTF using the rec 2020 colour space with a bit depth of 10 bits along with optional descriptive static metadata (SMPTE ST 2086) that may describe the maximum peak (MAXCLL) and maximum frame average (MAXFALL) brightness of the content.

HDR10+ adds descriptive dynamic metadata to HDR10 that describes the tone mapping curve that is preferred by the content creator on a reference mastering display, using curve parameters defined in SMPTE ST 2094-40 on a per scene basis

Dolby Vision is a proprietary HDR format from Dolby Laboratories that is based upon HDR10 and SMPTE ST 2084 for up to 4K resolution, and a wide-gamut color space (ITU-R Rec. 2020). It also supports 12-bit color depth and dynamic metadata that defines the tone mapping curve that is preferred by the content creator on a reference mastering display, using the curve parameters defined in SMPTE ST 2094-10 on a per scene basis.

SL-HDR1 tone maps an HDR signal (either PQ or HLG) into an SDR Rec 709 signal with dynamic metadata that allows inverse tone mapping at the receiver. [refs]

6.3. Audio System Discussion

Multiple next-generation audio systems have been documented by SCTE.

Considering that next generation audio systems *may* accompany HDR video services and products – and those audio systems have already been documented by SCTE – further discussion of those systems is omitted from this document except as necessary.

6.4. End-to-End System Considerations

There are many end-to-end system considerations that *may* be developed by other SDOs and will be specified by SCTE as modified by 'constraints'. Items such as SMPTE mastering and metadata formats, ingestion of content sources, production and ATSC signal and transport format(s), consumer sink device considerations and interfaces such as HDMI may be addressed in, or constrained by, SCTE for use in cable.

Generally, SCTE (and this document) will focus on cable distribution to the consumer.

6.5. Metadata

There are several types of "non-essence" data, commonly referred to as metadata. There are transport signaling metadata, such as traditional MPEG system information [30], for example identifying the types of signals in a stream. Some HDR metadata may provide enhancement or assistance to video decoding (such as improved fidelity for certain displays) that may be important but not essential for a given HDR presentation. However, there are also *new forms* of metadata such as program metadata which is used as navigation and content discovery elements for a user interface. All of these forms of metadata *should* be taken into account and are as important as static and dynamic metadata as needed for HDR systems to function and properly render content correctly.

Within the context of existing MPVD systems, there is a practical concern that metadata is not consistently passed by intermediate segments of the delivery chain. This reality may have severe consequences for downstream decoders. Thus, in the initial implementation of HDR systems (for cable) those concerns are sufficient to warrant that an end-to-end system *shall* continue to operate and provide an HDR experience consistent with the input source even without any expected HDR metadata (ergo, HDR content would remain HDR, whereas SDR content in an HDR experience would remain SDR). As defined herein for initial deployment, the absence of HDR picture metadata may cause a change of HDR mode or cause an impact to the consumer experience that needs to be taken into account by the system operator. To that end, system operators wish to consider systems that are resilient to the loss of the metadata that allows an HDR experience to continue. Future systems that may include metadata *should* not impact or degrade deployed systems (i.e. 'backward compatible').

Accidental deletion or inability to preserve HDR metadata should be considered a short-term limitation and subsequent evolution(s) of HDR systems *should* be designed to preserve all aspects of metadata ("run") through an entire end-to-end system.

6.6. Signaling and System Information

Signaling and system information *shall not* 'collide' with legacy systems and *should* enable future versions of next-generation systems to evolve.

6.7. User Experience and Interface Considerations

In addition to proper decoding and display of audio and video, the user experience is now an equally important aspect of content presentation to consumers. Systems should properly process graphics, user interface elements, picture-in-picture, subtitle and caption overlays in STB (external) implementations consistently with app-based (internal) implementations (i.e. native in display device rendering).

See requirement 7.2.3

7. System Use Cases

The formulating group within SCTE, including content producers, programmers, broadcasters, vendors and cable operators, engaged in extensive discussion of both the large scale content ecosystem and the specifics of modern cable systems and developed the use cases and associated requirements necessary to successfully deploy next generation video services to cable subscribers. These requirements, shown in tabular form, are intended to serve as the technical basis for selecting an initial approach for an SCTE HDR video standard. As stated in the introduction to this document, the technology is evolving at a rapid rate, and we anticipate that standards and deployments will follow a crawl/walk/run level of technical and economic complexity to accomplish an early deployment, but taking precautions not to exclude future improvements.

7.1. Provide the Highest Quality HDR Delivery to Consumers

Attract content owners and programmers best content and ensure that Cable remains competitive with other delivery systems.

	Consideration in Single vs Multiple HDR system(s)	Consideration in selecting a particular HDR System(s)
7.1.1. Support content provider/ MVPD trusted relationships into HDR Technology		
7.1.1.1. HDR quality on cable services *shall* be commensurate with the best other sources of HDR content (e.g. Blu-ray, OTT services) while working with the constraints of bandwidth to offer subscribers a wide variety of HDR services	Would different services or programs have noticeably different quality? Consumer awareness and visibility?	PQ EOTF with BT.2020 container, with BT.2100 color space; aligned with UHD Alliance "UHD Premium" specs
7.1.1.2. Deliver programmers HDR content without substantial degradation. Signals may be provided on a fiber interface or via satellite/IRD	Impact of (possibly multiple) HDR system conversions	Impact of HDR system conversions PQ EOTF with BT.2020 color space
7.1.1.3. Support retransmission of local broadcast HDR content (ATSC 3.0 signals) without substantial degradation. (Signals *may* be provided on a fiber interface or by receiving the over-the-air signal with an antenna. In cases where fiber interface is used, the over-the-air signal is often used as a backup)	Impact of (possibly multiple) HDR system conversions	Impact of HDR system conversions PQ EOTF with BT.2020 color Use YCbCr colour in narrow range, ICtCp in full range 1. Dynamic metadata MUST NOT be required but is an option Loss of metadata must default the system to HDR10 like performance

		Consideration in Single vs Multiple HDR system(s)	Consideration in selecting a particular HDR System(s)
7.1.1.4.	Cable HDR standard *shall not* substantially degrade content production transfer characteristics (Slog3,PQ, HLG) and color space	Impact of (possibly multiple) HDR system conversions	PQ EOTF with BT.2020 color space 1000 nits is a safe harbor for current productions Impact of HDR system conversions
7.1.2.	Support Distribution of both SDR and HDR content that preserves "creative intent" of both renderings		Cable systems will have separate HDR and SDR linear channels and VOD assets Dynamic metadata MUST NOT be required but is an option Loss of metadata shall default the system to HDR10 like performance
7.1.2.1.	"Standard dynamic range" (SDR) content can be integrated into an HDR program feed for cable transmission purposes with no perceptible change from the original SDR visual quality.	Impact of HDR system conversions	Not a standards issue; follow appropriate RPs to put SDR into HDR "container"
7.1.2.2.	Live linear channels *must* be simulcasted alongside legacy services/formats (in order to grow a new HDR user base while still supporting the existing SDR user base for video services)		

7.2. Smooth Transition - Integration Into Current Operator Infrastructure & Workflows

	Consideration in Single vs Multiple HDR system(s)	Considerations in selecting a particular HDR System(s)
7.2.1. Provide existing MVPD video services using HDR technology with HEVC Main10 compression		
7.2.1.1. Linear channels, including live productions (e.g., sports, news, events, etc)	N/A (but see channel change below)	N/A Creating HDR and SDR feeds is a Production issue, out of SCTE scope
7.2.1.2. VOD services, with rapid availability of "just aired" content	Impact of HDR System conversions • Quality • Complexity • Latency	Impact of HDR System conversions • Quality • Complexity • Latency
7.2.1.3. DVR services, both STB-based and cloud based architectures	Impact of HDR System conversions • Quality • Complexity • Latency	Impact of HDR System conversions • Quality • Complexity • Latency
7.2.1.4. Integration of third-party OTT services	What HDR system(s) are used by OTT services?	What HDR system(s) are used by OTT services? Is conversion necessary?
7.2.2. HDR assets shall be rapidly repurposeable from live to cDVR (Cloud DVR) to VOD services	Impact of HDR System conversions • Quality • Complexity • Latency	
7.2.3. Support existing MVPD video overlay experiences with integration of HDR technologies		

7.2.3.1.	A single HDR graphics overlay system *shall* be applied for all content. Graphic overlays (navigation, CC, etc) *shall* have a consistent brightness and color representation (no variation in time or across channels).	Single HDR graphics overlay system Support an HDR signal that is SDR like (different from SDR reconstruction)	Graphic overlays shall have a consistent brightness and color representation (no variation in time or across channels
7.2.3.2.	Support and identify HDR services and individual programs in EPG/ guide	EPG cannot be display-capability-dependent	N/A
7.2.3.3.	Support Emergency Alerts in HDR services (alerts, crawls, force tunes)		Graphic overlays shall have a consistent brightness and color representation (no variation in time or across channels)
7.2.4.	Support Existing MVPD video workflows with integration of HDR technologies		
7.2.4.1.	Support HDR contribution and mezzanine source feeds (production, servicing)	Complexity of distribution workflows	Quality differences of distribution workflows
7.2.4.2.	Support Stream identification & manipulation of HDR streams across cable networks (systems signaling)	System signaling of all HDR streams as a group	System signaling of different HDR streams
7.2.4.3.	HDR assets and feeds should be verified, securable, and distributable	Encryption Reconversion Issues & Location of re-encryption limitations	Encryption Reconversion Issues & Location of re-encryption limitations

7.2.4.4. HDR services must be capable of delivery over MPEG-2 TS (and vice-versa TS into segmented DASH (HLS))		Probably TC agnostic Dynamic metadata?
7.2.4.5. Support audience measurement, watermarking (forensics) and content security	Can not have HDR system-specific solutions	Dynamic metadata?
7.2.5. Support local and national ad insertion campaigns in HDR Services		
7.2.5.1. Support server side ad insertion for HDR linear channel, DVR playback or HDR VOD asset (STB QAM or COAM or other device)	Minimize the number of content versions needed for HDR ad insertion	Does ad insertion create any degradation or disruption?
7.2.5.2. Support client side ad insertion for HDR linear channel, DVR playback or HDR VOD asset	Minimizing the number of content versions supported for HDR ad insertion	

7.3. Support the Existing Consumer Experience

	Consideration in Single vs Multiple HDR system(s)	**Consideration in selecting a particular HDR System(s)**
7.3.1. Support fast and seamless service navigation		
7.3.1.1. Multi-channel mosaics, picture-in-picture	Can it practically be achieved with multiple HDR systems?	Impact of HDR system conversions • Quality • Complexity • Latency
7.3.1.2. Fast channel change across linear channels and fast content startup (VOD/DVR) – no HDMI resets	No HDMI resets	SDR “Unity Gain”? - Does SDR <-> HDR switching

		require an HDMI reset?
7.3.1.3. Need to support Slates. (Loss of Signal or 'blackout' messages to consumers)	Storage of multiple versions of Slates. Signaling of Slates	N/A
7.3.2. Provide for smooth playback of HDR services on playback device such as COAM, STB, and IP players.		
7.3.2.1. No device HDMI resets on channel change across linear channels. Discovery of TV HDR capabilities to decoding and/or separate display device to avoid HDMI resets while maintaining a consistent quality user experience.	No HDMI resets	If Dynamic metadata is used, how is it rendered, or conveyed to display (HDMI, IP, etc)? Is time synchronization assured?
7.3.2.2. Support HDR services across linear channels across a range of devices for COAM, set top box, and TV Everywhere services.	Increase expense of COAM devices (i.e Multiple CTA wave profile devices)	Should an HDR service be an APP on an approved hardware device
7.3.3. Consistent (but improving) HDR viewing experience		
7.3.3.1. Support standard conversions from production (broadcast/file) to distribution workflows		We need to promote competition and interoperability with conversion equipment. Especially conversion equipment that went through stages (LUTs , FS/NS)
7.3.3.2. HDR services should operate across different levels of devices (STBs & TVs) with different display adaptive performances	No HDMI resets	Maybe a discussion and decision of descriptive versus

	Consistency of consumer experience	prescriptive signal information?
7.3.3.3. Support content production that may change the peak brightness leveling for mastering processes over time.	Impact on consistency of consumer experience?	If new content with different peak brightness is introduced, what is the effect on navigation, ad insertion, graphics overlays and other requirements?

7.4. HDR Technology Longevity and Extensibility

	Consideration in Single vs Multiple HDR system(s)	**Consideration in selecting a particular HDR System(s)**
7.4.1. Support next generation MVPD video services with HDR technologies.		
7.4.1.1. HDR services should be of noticeably better quality than corresponding SDR services	Different types of HDR noticeable to consumers?	HDR should be noticeable from a distance with respect to SDR.
7.4.1.2. *Should* support other next generation technologies including audio (object audio), subtitling (e.g. IMSC1), graphics	CC and graphics rendering quality, consistency	CC and graphics rendering quality, consistency
7.4.1.3. Metadata (where used) *should* be easily aligned (synchronized) with HDR feeds or assets (static, dynamic) e.g. future distribution should NOT presume that metadata "falls on the floor".		If metadata is used: 1. Is a lack of metadata catastrophic? How do you validate metadata to the video?

	Consideration in Single vs Multiple HDR system(s)	Consideration in selecting a particular HDR System(s)
7.4.1.4. New video service features such as 360 view/VR should anticipate an HDR viewing mode	Anticipate the fusion of multiple sources into a VR? Impact of HDR system conversions	Does the system have characteristics that prevent or complicate scene stitching across multiple cameras?
7.4.1.5. HDR services shall be deliverable over DASH/IP	N/A	Extent of support in devices and apps? One set of media segments? How many adaptation sets are needed with more flavors?
7.4.2. Provide longevity in HDR video services		
7.4.2.1. Anticipated lifetime of technology *must* be as long as possible	Complexity required to support evolution of multiple HDR systems across range of consumer devices?	What are the limitations of the proposed system in peak brightness, color gamut, quantization or other factors? How quickly might the system be "outgrown"?
a. ***Accommodate future performance improvements in a compatible manner***, for discussion: - Level 1 advancements without changes to the decoding of the bitstream (allows for post-processing) - Level 2 advancements with changes to the decoding of the bitstream (but then there is no backwards compatibility)	X	What are proposed or anticipated improvements to the proposed system?

		Consideration in Single vs Multiple HDR system(s)	Consideration in selecting a particular HDR System(s)
7.4.2.2.	HDR technology *shall* be supportable and migratable in a catalog archiving system	Impact of HDR System conversions • Quality • Complexity • Latency	Can future improvements be implemented with addition of supplemental metadata? Should there be only HDR format for each asset? But does it need to be same HDR format for each time?

8. Selection and Criteria Discussion

Systems have been evaluated on their conformance to these requirements during the course of developing and discussing each requirement.

9. Summary and Recommendation

9.1. Conclusions

In the context and timeframe required for a timely initial launch and "Phase 1 deployment" of HDR video services by the cable industry for distribution, consideration of the many technical requirements summarized in this report lead to the following conclusions:

1. **Cable systems require a single HDR video system** - The practical technical constraints currently imposed by ad insertion, user interfaces and HDMI connections, do not support the use of multiple HDR video systems in a cable plant. In particular, operators should provide the same advanced user navigation experiences in HDR video services that are available in current services, which include merging content in multi-channel mosaics, picture-in-picture, graphic overlays, and other special effects.They should be implemented consistently on both set top box and application/smart device delivery paths. As one example of a visual consistency issue, different HDR schemes use different tone mapping and transfer function processing algorithms, which may result in a visible mismatch in light levels and contrast points. Further, as a longer term consideration, the use of multiple HDR systems within a cable plant may significantly increase operator complexities and costs while providing no benefit to subscribers. To the extent that some content may only be available in a different HDR system format than used in a cable plant, it may be "conformed" at the input to the plant (in other words, a single "house format" will be used, just like is done for other formatting aspects of the video signal). (Which party is responsible for HDR system conversion and associated quality metrics will be a matter of commercial negotiation that is beyond the scope of this document.)

2. **The cable industry requires a single HDR video system [for timely launch]** - While the selection of a "house" HDR video system could in theory be made independently by each cable operator, the result would be to fragment the cable industry and its content and technology supply chains, which would have many negative consequences. First, content and advertising providers would have to produce and deliver in multiple HDR video systems, or alternatively, many conversions would be required within cable operators' plant and workflows. The resulting complexities, quality and consistency concerns would inevitably delay and slow down the launch and adoption of HDR video services by the cable industry. Second, technology suppliers in every aspect of cable delivery, including systems, devices, set top boxes, integrated circuits, and application software would be required to design, test and verify the performance of multiple HDR video systems (including cable-specific complexities such as graphic overlays and picture-in-picture), which would consume unnecessary time and resources, delaying a timely launch.

3. **The HDR video system should provide the best possible performance for launch** – The selected HDR Video system *shall* be capable of delivering the highest possible technical quality, as represented by currently practical peak brightness, wide color gamut and most precise representation of the color volume.

4. **The HDR video system should facilitate a timely launch –** A timely launch of HDR Video services by cable operators will require the availability of sufficient compelling HDR content and the availability of devices that are capable of rendering that HDR content. Interoperability with pre-existing formats for HDR distribution such as Blu-ray and internet-streaming will help to ensure the availability of high quality content libraries without the need for re-mastering or conversion for cable distribution. It will also help to ensure the availability of the required technology and equipment. Interoperability with television, computer, tablet and phone decoding and display capabilities is also crucial to ensure the largest potential audience for new HDR video services.

5. **Dynamic metadata is not practical for launch –** The current technical standards and infrastructure to ubiquitously support dynamic metadata are not a practical reality at the current time in any of the cable ecosystem sectors (e.g., content production, programmers, and cable systems). As a longer-term consideration, it is uncertain how dynamic metadata should be applied in conjunction with advanced user navigation experiences. It will take time to explore and resolve such issues, so dynamic metadata should be considered in later phases of HDR video standardization and deployment.

6. **The HDR video system should be as future-proof as possible** – This is partly achieved by selecting the highest-performing system that is currently deployable for a timely launch, as represented by the limitations on peak brightness, wide color gamut and precision of representation of the color volume that are characteristic of an HDR video system. Although not practical for launch, it is highly desirable that future performance improvements should be achievable with the addition of optional dynamic metadata.

9.2. Drafting Group Consensus Recommendation

The consensus of the drafting group members is that HDR10 meets the requirements of the cable industry for an HDR video distribution standard. Any other HDR format used for content or advertising can be converted without loss. It is used by both Blu-ray and Internet streaming providers and by the UHD Alliance “UltraHD Premium” specifications, which ensures the availability of high-quality content in the format and the availability of technical systems products that will meet the needs of the cable industry. And its processing and display is supported across the widest variety of currently available and next-generation television, computer, tablet, and phone devices. Its performance many be improved in the future with the optional inclusion of dynamic metadata, as the ability to create and deliver it becomes a practical possibility in the content production and distribution ecosystem. SCTE should proceed expeditiously to standardize HDR10 for cable systems. The HLG HDR system, which operates simply without HDR metadata of any kind to complicate the various cable system workflow and processing systems, is also a potentially valid solution to some of the issues identified in this document, and should be evaluated along with other HDR systems and metadata based enhancements to HDR10 in future phases of HDR standardization.

9.3. Drafting Group Non-Consensus (Minority) Commentary

During the formulation of this document at least one drafting group member has indicated that HLG meets the requirements outlined in this document.

