Initial Report of the UHDTV Ecosystem Study Group

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This report provides an overview of image and audio technology standards and requirements for UHDTV production in the professional broadcast domain. This report represents a SMPTE study primarily focused on real time broadcasting and distribution and is therefore not an exhaustive analysis of UHDTV1 and UHDTV2.

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Introduction

This report represents the initial considerations of the SMPTE study group investigating the UHDTV Ecosystem. The report provides recommendations for further work, which will be further analyzed within SMPTE.

The industry has developed technologies for increasing image pixel arrays, capturing higher frame rates, extended color gamut and other image parameters beyond those currently defined for HDTV.
Image formats for Ultra-High Definition television have been approved by the SMPTE[1] and the ITU-R[2]. It has been indicated that commercial deployment of UHDTV could begin as early as 2014 for UHDTV1 and 2016 for UHDTV2. While the intent is distribution of the format to the home, overall questions for the professional industry sector are:

(a) How to interchange these new formats in the professional real-time or non-real-time domain (considering uncompressed, mezzanine or contribution quality), and
(b) Which exchange and interface standards are needed.

To avoid confusion with terminology, a glossary of UHDTV terms is also provided.

NOTE: *this report makes reference to a number of documents that are currently in development within SMPTE. Such documents - prefaced with the word "Proposed" - may not be publically available at time of this writing.*

Scope of this report

This report will provide a short overview of image and audio technology standards available. It is not an exhaustive analysis of UHDTV1 and UHDTV2 but rather it represents a SMPTE study primarily focused on real time broadcasting and distribution, intended to highlight available standards and to make recommendations for further standards and technology development work.

It will then determine the requirements and impact on interfacing/exchanging formats defined by SMPTE ST 2036-1 ("UHDTV1" and "UHDTV2") and ITU-R Recommendation BT.2020 (BT.2020), in an end-to-end chain (e.g., with a reference diagram visualizing the areas where exchange standards are needed).

The report will focus on professional real-time infrastructure with ancillary reference to non-real-time-infrastructures for producing and processing content for distribution via television and broadband distribution. Compatibility to interface technologies expected for the end user environment may be taken into account. The report will provide recommendations for future standardization work but will not define these new standards.

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1 SMPTE ST 2036-1:2009 Ultra High Definition Television – Image Parameter Values for Program Production
2 Recommendation ITU-R BT.2020 (2012) Parameter values for ultra-high definition television systems for production and international programme exchange

This report will focus on the 3840x2160-pixel array of UHDTV imaging described in SMPTE ST 2036-1. Consideration is also given to audio requirements and of the potential requirement for higher frame rates (beyond 60 Hz) for specific applications.

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Section 1 - What is UHDTV

As with many new technology names and acronyms, there is typically a range of understanding and interpretation as to what a name means, and the term "UHDTV" is no exception.

It should be noted that the term "Ultra" is often prepended to new technology names to indicate an evolution to something higher in performance than the previous technology it expands upon. This is particularly evident in consumer products where there becomes a mix of similar terminologies (e.g., “4K” and “Ultra”) used to define sometimes diverse technologies.

The most formal use of the term Ultra High Definition Television is that used in the SMPTE standards ST 2036-1:2013 (program production image parameters); ST-2036-2-2008 (for audio) and ST 2036-3:2012 (digital interface and mapping). These documents define UHDTV1 (3840x2160 pixels) and UHDTV2 (7680x4320 pixels), and provide constraints on spatial and temporal resolution, color space, bit depth and audio channel structure to the specific parameters described in those standards.

This report chooses to place a "stake in the ground" and focus on a specific definition of UHDTV namely UHDTV1. This focus does not mean to restrict or exclude discussions of advancements beyond the definitions of UHDTV that is described in the next sections. However, in order to move the work of the Study Group forward and provide recommendations in a timely fashion, the UHDTV Ecosystem discussed here is centered on the constraints listed in Table 1. What follows is this report's definition, and answer to, "What is UHDTV?"

Section 2 – Image

Image characteristics for UHDTV1 systems as defined in ST 2036-1 are as shown in the table below repeated from ST 2036-1.

Table 1 – Image sample structures and frame rates of UHDTV systems

System category	System nomenclature	Luma or R’ G’ B’ samples per line	Lines per frame	Frame rate (Hz)
UHDTV1	3840 x 2160/23.98/P	3840	2160	24/1.001
	3840 x 2160/24/P	3840	2160	24
	3840 x 2160/25/P	3840	2160	25
	3840 x 2160/29.97/P	3840	2160	30/1.001
	3840 x 2160/30/P	3840	2160	30
	3840 x 2160/50/P	3840	2160	50
	3840 x 2160/59.94/P	3840	2160	60/1.001
	3840 x 2160/60/P	3840	2160	60
	3840 x 2160/120/P	3840	2160	120

2.1 Image Structure

The following discussion is primarily applicable to serial digital interfaces, but may be applicable in some file formats.

2.1.1 Pixel Array

UHDTV1 consists of an array of pixels 3840 x 2160, which are uniformly spaced, orthogonal and have a pixel aspect ratio of 1:1 (square pixels). The aspect ratio of the image is 16:9.

2.1.2 Image Sync and Blanking

When carried on a serial digital interface, horizontal ancillary data areas and vertical ancillary data area are appended to the UHDTV1 pixel array.

These areas or spaces are required for synchronization and are also used to carry audio and other ancillary data streams.

For file formats such as MXF, the information contained in horizontal ancillary data and vertical ancillary data areas are separated from the image raster and stored separately in a manner that permits reconstruction of a properly formatted serial digital signal as required.

2.2 Colorimetry

UHDTV1 reference primaries as defined in ST 2036-1 are shown in Table 2.

For backwards compatibility with HDTV systems, ST 2036-1 allows implementers to optionally adopt conventional reference primaries for UHDTV1, which are consistent with Recommendation ITU-R BT.709 (BT.709), as shown in Table 3. The colorimetry employed must be signaled on the interface.

(1) This study group recommends that further work be undertaken to ensure that the employed UHDTV1 colorimetry is signaled in the interface.

	CIE x	CIE y
Red primary	0.708	0.292
Green primary	0.170	0.797
Blue primary	0.131	0.046
Reference white	0.3127	0.3290

Table 2 UHDTV1 reference primaries and reference white[3]

[3] These values are consistent with Recommendation ITU-R BT.2020

	CIE x	CIE y
Red primary	0.640	0.330
Green primary	0.300	0.600
Blue primary	0.150	0.060
Reference white	0.3127	0.3290

Table 3 Conventional reference primaries and reference white[4]

The supported color gamut for each set of reference primaries is illustrated in the diagram of Figure 1.

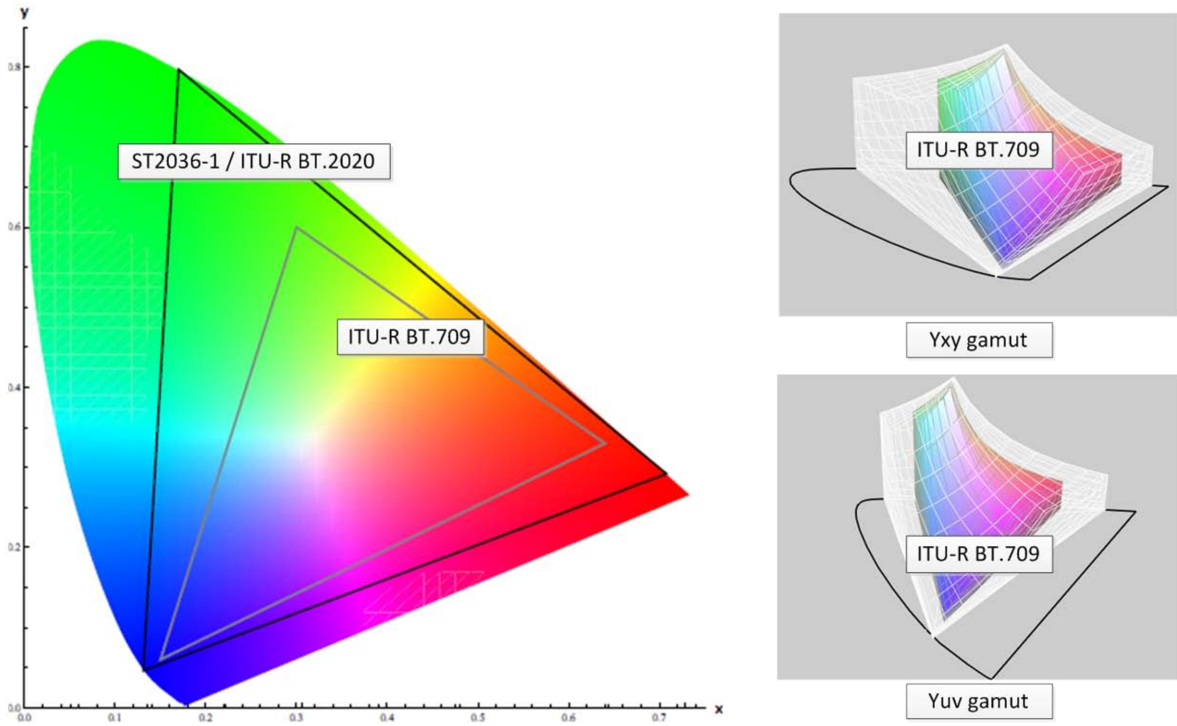

Figure 1 UHDTV supported color gamut in both xy and uv

ST 2036-1 specifies conventional non-constant luminance processing in $Y'C'_BC'_R$ format.

BT.2020 provides the option of constant luminance processing in Y'_C, C'_{BC}, C'_{RC} format.

Report ITU-R BT.2246-2[5] 2012 (BT.2246) - The present state of ultra-high definition television – provides a detailed discussion on the use and application of constant luminance coding.

[4] Conventional reference primaries may be optionally used by UHDTV1. These reference primaries are consistent with Recommendation ITU-R BT.709.

[5] ITU-R BT.2246-2 (2012) The present state of ultra-high definition television http://www.itu.int/pub/R-REP-BT.2246

The conclusion of the work carried out in the ITU was that there was no practically visibly perceptible advantage in using constant luminance processing in the production environment.

(2) This study group recommends no change be made with regards to the conventional non-constant luminance parameters defined by ST 2036-1.

2.2.1 – Color Space Conversion

As previously noted SMPTE ST 2036-1 and BT.2020 specify a common expanded color space for UHDTV1 and UHDTV2 formats. ST 2036-1 optionally allows BT.709 color space to be used for production and to date UHDTV1 productions have been largely created using this legacy color space only.

The UHDTV color gamut is significantly larger than either BT.709 or Recommendation ITU-R BT.601 (BT.601). The new color gamut volume (in XYZ space) is twice the BT.709 color gamut volume. Thus, compared to BT.709, UHDTV encompasses approximately twice more, but far from all, colors perceived by humans or colors that can be captured by a camera. UHDTV workflows and devices that solely support the UHDTV color space should be able to support an equivalent level of color interoperability and accuracy as BT.709 workflows and devices do today.

However, it is envisioned that the industry will experience a transition period when moving to the extended UHDTV color space for production and post-production. Color conversion to and from legacy BT.709 and BT.601 color spaces to comply with legacy workflows will be required.

(3) This study group recommends that SMPTE undertake further work to study the issues and requirements for color space conversion to and from UHDTV color space and legacy Color space. This study should also consider the requirements to standardize colorist metadata

Further information on color space conversion and gamut mapping is provided in Annex C.

2.3 Sampling and bit-depth

UHDTV1 systems employ either R'G'B' or $Y'C'_BC'_R$ components and may be sampled as 4:4:4, 4:2:2 or 4:2:0. Each component may be sampled at a bit-depth of 10-bits or 12-bits. The sampling and bit-depth employed must be signaled on the interface.

2.4 – Frame Rates

UHDTV1 systems are progressively captured at frame rates of 24/1.001 fps; 24 fps; 25 fps; 30/1.001 fps; 50 fps; 60/1.001 fps; 60 fps or 120 fps.

2.4.1 – Fractional Frame rates (1/1.001)

The maximum frame rate of 120 fps specified in ST 2036-1 (and BT.2020) is intended as a single worldwide high frame rate for UHDTV1.

At lower frame rates fractional 1/1.001 rates are allowed for UHDTV1 , which raises concern over the conversions from 120Hz to any of the lower **1.001** frame rates as sophisticated frame rate conversion could be required to minimize alias and judder rather than simple frame drop / or repeat processing. Standards conversion of material sourced at 120 Hz to 50 or 59.94 Hz legacy HD systems and the conversion of archive material up to 120Hz is a reality in any broadcast operation. Temporal artifacts in frame rate conversion are undesirable, especially so for sports events when slow motion or freeze frames are concerned. Motion compensated frame rate conversion for HDTV production is continuously improving but it is recognized that current implementations may be significantly challenged by the processing bandwidths required for UHDTV1 images at 120Hz.

The signal processing issues will be overcome in time, however there are many other practical issues such as cost, complexity and latency in a mixed UHDTV/HD/SD live environment that may be very challenging to overcome.

Broadcasters find it convenient today to embrace the 1/1.001 frame rates as they can convert legacy material into HDTV productions without temporal artifacts, with minimal latency and low cost.
For pragmatic and commercial reasons then, it may be desirable that UHDTV1 support 120/1.001 fps.

(4) This study group recommends that further work be undertaken to consider the implications of converting between 1/1.001 and the integer frame rate of 120Hz.

2.4.2 – Frame Rate Study

As previously noted, the integer frame rate of 120 fps is intended as a single worldwide high frame rate for UHDTV1. It implies equal pain in the conversion to and from the commonly used frame/field rates of 50 and 59.94 fps. The implications of this, and its long-term advantages (of simplification and potential cost savings for both standards and equipment) as compared to retaining the present split between the 50 and 59.94 worlds, is an area in need of further study, particularly in the area of standards/frame-rate conversion, and lighting flicker.

Research continues in a number of organizations into additional frame rates with varying degrees of improvements. No definitive conclusion has yet been reached on which if any additional frame rates should be considered for UHDTV production.

(5) This study group recommends no change be made to the UHDTV1 frame rates supported by ST 2036-1.

Further information on additional / alternate UHDTV frame rates is provided in Annex D.

2.5 –Stereoscopic 3D

As UHDTV is an extension over existing HDTV which nowadays includes Stereoscope 3D, it is important to spend some time foreseeing potential impacts if any. SMPTE has a number of standards specific to stereoscopic 3D either published or in preparation. For example:

Full Resolution Contribution Links ST 2063:

Live Stereoscopic 3D events must be sent typically to a central distribution point or facility. This needs to be Full Resolution images, because additional production is typically carried out before emission to viewers. This standard provides the important constraints for such systems.

Frame Compatible ST-2068:

Frame compatible technology is instrumental in stereoscopic 3D deployment since the beginning. It allows progressive and quick deployment at minimal cost. In this sense, UHDTV1 implementers may want to use such a technology shortcut.

Production Timing and Sync ST-2076:

Production timing and sync mechanisms were developed to achieve perfect synchronism between right and left cameras. This standard provides important foundational information that facilitates UHDTV1 and other formats for 3D production.

Disparity Map Representation ST-2066:

Document ST-2066 is a standard for data representation of Disparity Map for Stereoscopic 3D. This document already includes references and mechanisms to support UHDTV1 resolution. There is no foreseeable impact on the network.

Stereoscopic 3D in MXF ST 2070-1:

This document defines metadata and the index structure of stereoscopic 3D video streams in MXF for operational applications. This standard currently supports streams of stereoscopic images, either as uncompressed image pairs, inter-frame compressed formats as well as Long GOP formats.

Section 3 – Audio

With the enhanced visual experience of UHDTV, there is an opportunity to extend the accompanying audio experience to improve immersion, audio quality, and “wow factor” in order to give the consumer a premium overall experience.

While the current 5.1 and Stereo audio configurations will continue to be delivered, the overall quality and resolution of audio should aspire to the level of the UHDTV visual experience. In addition to these current audio configurations, newer audio systems are coming forward that should be considered for use in UHDTV.

ST 2036-2 documents a 22.2 audio channel system for UHDTV, and since the time that document was written, additional “immersive audio” systems have come to market for cinema, such as 9.1, 11.1 and “object based” formats.

The manufacturers of these systems are working with SMPTE, MPEG-H, ITU, AES, BDA and other industry organizations to determine the best way to bring immersive audio to the home while insuring compatibility with current home systems. As of this writing, there are proposals being brought forward, but no set standard yet exists.

NOTE: MPEG-H has requested a liaison on immersive audio with TC-24TB and TC-25CSS, and ITU-R has also expressed interest though no formal liaison has been requested to date.

Additional information on extended or immersive audio requirements is included in Annex B of this document.

Infrastructure requirements and *recommendations for additional* work regarding UHDTV Audio are discussed in section 4.3 of this report.

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Section 4 UHDTV Ecosystem

The diagram of figure 2 illustrates a notional television production / broadcast facility.

For the purposes of this report, the diagram is used to explore operational requirements for facilities and to identify any special needs relating to the interchange of material when transitioning to UHDTV1 production and for mixed UHDTV1 / HDTV / SDTV production.

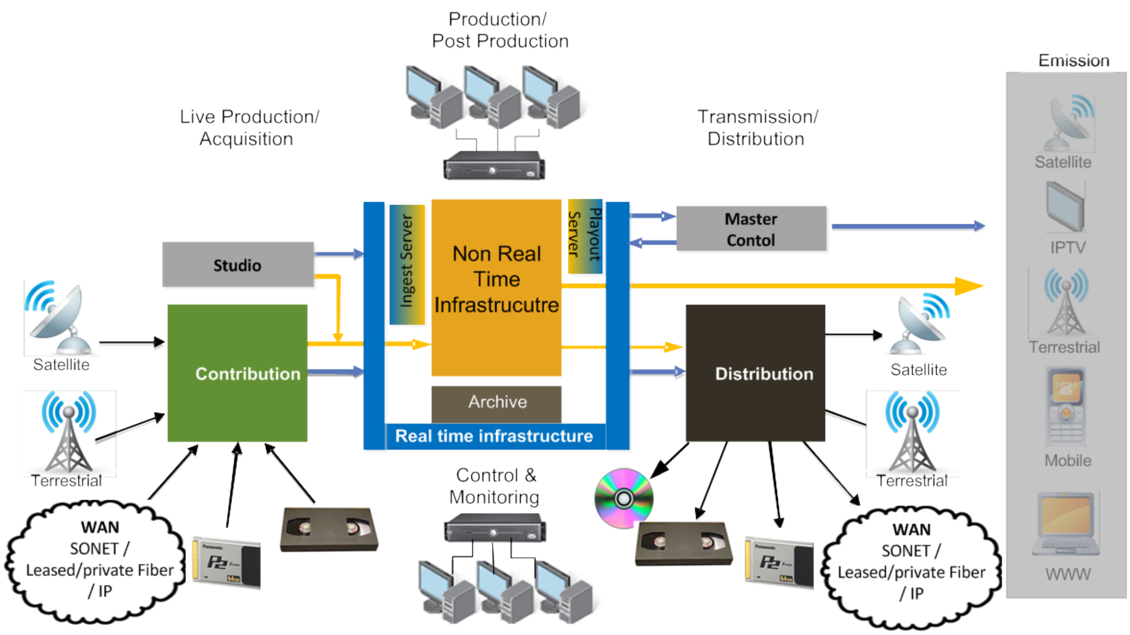

Figure 2 UHDTV Ecosystem Reference Diagram

4.1 – Real-time streaming media interfaces (SDI)

Emerging requirements for UHDTV1 production gives rise to an explosion in required real-time multi-media streaming bandwidth. Table 4 lists the payloads and real-time streaming interface rates for UHDTV1 production image formats.

Horizontal Pixels	Vertical Pixels	Frames per Second (nominal)	Total Payload (nominal)	
			10-bit 4:2:0 10-bit 4:2:2	12-bit 4:2:0 12-bit 4:2:2 12-bit 4:4:4 10-bit 4:4:4:4
3840	2160	120	24Gbit/Sec	48Gbit/Sec
3840	2160	60	12Gbit/Sec	24Gbit/Sec
3840	2160	50		
3840	2160	30	6Gbit/Sec	12Gbit/Sec
3840	2160	25		
3840	2160	24		

Table 4 UHDTV1 Image formats and payloads

But existing broadcast infrastructure has only recently migrated to 3G-SDI creating a bandwidth disparity within the existing core infrastructure.

Multiple options have been proposed, are in development or are being explored to address the disparity between emerging bandwidth needs and the bandwidth constrained core broadcast infrastructure.
It should be noted however that at time of writing there are no real-time streaming media interface standards that support UHDTV1 image formats and payloads at 120 fps.

(6) This study group recommends that further work be undertaken to develop real-time streaming media interface standards in support of UHDTV1 image formats and payloads up to 120 fps.

4.1.1 – Multi-link 3G SDI

Dual-link and Quad-link 3G-SDI Interface standards are under development by the SMPTE.
By introducing an evolutionary development of the SDI interface that is backwards compatible with the existing 3G-SDI core infrastructure, SMPTE is providing broadcasters with the means to meet emerging production requirements without having to replace their core SDI infrastructure.

Eventually, as UHDTV1 production moves from "application and infrastructure islands" to mainstream production requirements, a new core-infrastructure and real-time media streaming interface data rate and build out will be required.

The 32NF40 Multi-link 3G AHG is currently in the process of developing standards for 2D image formats with nominal payloads of 6Gbit/Sec and 12Gbit/Sec as illustrated in Table 5.

<table>
<tr><th rowspan="2">Horizontal Pixels</th><th rowspan="2">Vertical Pixels</th><th rowspan="2">Frames per Second (nominal)</th><th colspan="2">SDI Standard</th></tr>
<tr><th>10-bit 4:2:0
10-bit 4:2:2</th><th>12-bit 4:2:0
12-bit 4:2:2
12-bit 4:4:4
10-bit 4:4:4:4</th></tr>
<tr><td>3840</td><td>2160</td><td>120</td><td></td><td rowspan="3"></td></tr>
<tr><td>3840</td><td>2160</td><td>60</td><td rowspan="2">ST 425-5
Quad Link 3G</td></tr>
<tr><td>3840</td><td>2160</td><td>50</td></tr>
<tr><td>3840</td><td>2160</td><td>30</td><td rowspan="3">ST 425-3
Dual-link 3G</td><td rowspan="3">ST 425-5
Quad-link 3G</td></tr>
<tr><td>3840</td><td>2160</td><td>25</td></tr>
<tr><td>3840</td><td>2160</td><td>24</td></tr>
</table>

Table 5 3G multi-link Interface standards for UHDTV1 production

ST 425-3 Image Format and Ancillary Data Mapping for the Dual Link 3 Gbit/Sec Serial Interface, supports UHDTV1 production image formats with 4:2:2 / 4:2:0 sampling at frame rates up to 30 fps.

Proposed standard ST 425-5 Image Format and Ancillary Data Mapping for the Quad Link 3G-SDI Interface, supports UHDTV1 production image formats with 4:2:2 / 4:2:0 sampling at frame rates up to 60 fps, and 4:4:4 sampling and 12-bit pixel resolution at frame rates up to 30 fps.

4.1.2 – 10.692Gbit/Sec optical SDI interface

SMPTE standardized a 10.692Gbit/Sec optical SDI interface in 2007 as SMPTE ST 435 part 1 though part 3. This multi-part document suite defines the carriage of multiple (up to 8), 1.5Gbit/Sec virtual SDI links on a 10.692Gbit/Sec optical interface.

This standard defines: Basic Stream Derivation in part 1; Basic Stream Data Mapping in part 2 and the 10.629 Gbit/Sec Optical Fiber Interface in part 3.

As a 10G-SDI interface, ST 435 provides sufficient bandwidth to transport UHDTV1 production image formats with 4:2:0, 4:2:2 or 4:4:4 sampling, 10-bit and 12-bit pixel resolution at frame rates up to 30 fps as shown in Table 6.

Horizontal Pixels	Vertical Pixels	Frames per Second (nominal)	SDI Standard	
			10-bit 4:2:0 10-bit 4:2:2	12-bit 4:2:0 12-bit 4:2:2 12-bit 4:4:4 10-bit 4:4:4
3840	2160	120		
3840	2160	60		
3840	2160	50		
3840	2160	30	ST435-1 Single-link 10G	
3840	2160	25		
3840	2160	24		

Table 6 10G-SDI single-link Interface for UHDTV1 production

ST 435 also provides the basis for the carriage of UHDTV1 production image formats at frame rates up to 50/60Hz, the interfaces for which are defined in SMPTE ST 2036-3: Ultra High Definition Television – Mapping into Single-link or Multi-link 10 Gbit/Sec Serial Signal/Data Interface (Single, Dual, Quad and Octal DWDM optical interfaces).

ST 2036-3 directly leverage the basic stream and mapping concepts of ST 435-1 and -2 and utilises the 10G optical interface defined in part 3 as the basic building block for the single-link and multi-link DWDM (Dense Wave-length Division Multiplex), interface.

Table 7 shows the image formats supported by ST 2036-3 carried over single and multi-link ST 435 optical interfaces.

Horizontal Pixels	Vertical Pixels	Frames per Second (nominal)	SDI Standard	
			10-bit 4:2:0 10-bit 4:2:2 10-bit 4:4:4	12-bit 4:2:0 12-bit 4:2:2 12-bit 4:4:4
3840	2160	120		
3840	2160	60	ST 2036-3 Dual-link 10G	
3840	2160	50		
3840	2160	30	ST 2036-3 Single-link 10G	
3840	2160	25		
3840	2160	24		

Table 7 10.629Gbit/Sec interface standards for UHDTV1 production

4.1.3 - 25Gbit/Sec optical SDI interface

In addition to the 10G optical SDI interface, SMPTE is currently working towards publication of a (nominal) 25Gbit/Sec optical SDI interface as Proposed SMPTE ST2062 part 1 and part 2.

This standard defines: Source Image and Format Mapping in part 1 and defines the 25.79851 Gbit/Sec Optical Fiber Interface in part 2.

This standard also leverages the basic stream and mapping structures defined in ST 435. Operating at twice the serial rate of ST 435, ST 2062 provides sufficient single-link bandwidth for the carriage of UHDTV1 production image formats with 4:4:4 sampling, 10-bit and 12-bit pixel resolution at frame rates up to and including 60 fps.

Horizontal Pixels	Vertical Pixels	Frames per Second (nominal)	Total Payload (nominal)	
			10-bit 4:2:0 10-bit 4:2:2 10-bit 4:4:4	12-bit 4:2:0 12-bit 4:2:2 12-bit 4:4:4
3840	2160	120		
3840	2160	60	Proposed ST 2062-1 Single-link 25G	
3840	2160	50		
3840	2160	30		
3840	2160	25		
3840	2160	24		

Table 8 25Gbit/Sec interface standards for UHDTV1 production

At time of writing proposed standards ST 2062-1 and -2 have not completed the balloting and publication process although this standard is very close to completion.

4.1.4– 72Gbit/Sec optical SDI interface

ITU-R report BT.2246-2 makes mention of *"An optical transmission system was recently developed for the interface of UHDTV studio equipment*".

It carries 72 Gigabits per-second data that correspond to a 7 680 × 4 320 pixel, 60 Hz, 12-bit, 4:4:4signal.

A report on the development of this interface by M. Nakamura, T. Nakatogawa, and K. Oyamada, *"Development of Optical Interface for Full-Resolution Super Hi-Vision Production Systems",* is available from ITE Tech, Rep., Vol. 33, No. 32, pp. 5-8, July 2009.

As noted previously, this interface also does not support frame rates beyond 60Hz.

4.1.5 – Mezzanine Compression

To reduce the cost of UHDTV1 infrastructure build out, the use of a mezzanine compression system to extend the life of existing major infrastructure items such as SDI routers and existing IP-based networks in production islands may be very attractive.

Modest levels of compression in the range 2:1 to 20:1 (depending on image format and interface bandwidth requirements) could be employed to provide sufficient bandwidth reduction to accommodate the transport of UHDTV1 production image formats over the existing SDI infrastructure.

For example, such a system would convert the UHDTV1 baseband signal data rate of ~12Gbit/Sec (3180x2160 @50/60p) to 3G-SDI or even 1.5Gbit/Sec HDSDI.

The key attributes for a mezzanine codec to be used in live production are listed below:

- Low-delay coding and decoding (1 frame or less)
- Low-loss compression providing visually near-perfect reproduction.
- Multi-generation compression adds negligible concatenation errors and additional loss.

- A symmetrical encode / decode algorithm that should be relatively easy to implement both in hardware and software
- Support for full range of images (image sampling, resolution, frame-rate, bit depth and color gamut)
- Compression range ~ 2 to 20x

Similarly such a codec can also be used to decrease file sizes to improve storage efficiency and download times during production.
(7) This study group recommends that SMPTE undertake work to define specific mezzanine image compression profiles and bit streams that can be mapped to the SDI interface.

4.2. – Real-time Networked Media Interfaces

4.2.1 – Uncompressed Real-Time Networked Interface

As described in Section 4.2.1, the bandwidth requirements for the UHDTV1 image formats are at rates higher than existing single-link electrical SDI interfaces.

It is possible to carry uncompressed UHDTV1 images over Ethernet interfaces. Ethernet interfaces have been defined by the IEEE 802.3 working group at appropriate data rates for transmission.

In SMPTE 2022-6, SMPTE has previously standardized the carriage of high bit-rate media content (such as SMPTE ST 259, SMPTE ST 292-1 and SMPTE ST 424 streams) using RTP over IP that can be carried over Ethernet connections.

(8) This study group recommends that SMPTE continue to work on standardization for the carriage of uncompressed UHDTV1 image streams over packetized real-time network interfaces.

4.2.2 – Visually Lossless Real-Time Networked Interface

As previously discussed in Section 4.2.1.4, - Mezzanine Compression, the application of "visually lossless" compression to address the tremendous bandwidth requirements of UHDTV1 images, may be useful in professional applications. The definition of visually lossless should be defined precisely by SMPTE, but in general it should refer to compression that is unable to be reliably differentiated by expert viewers when compared with the original image after a number of concatenated encode/decode cycles.

Latency of encoding/decoding of the compressed stream would be a significant issue for live production. A codec with a minimal latency that could provide the required compression with appropriate computational complexity would be required.

4.3 – Infrastructure Requirements for audio

The current infrastructure as illustrated in the diagram of Figure 2 may require updates in order to handle the extended requirements for audio in general and also for immersive audio. Some key areas to be considered include:

1. Audio mixing facilities and sound design rooms may require upgrades to provide higher quality audio. In order to create immersive audio, they must be outfitted with proper mixing and monitoring equipment. Mixing engineers and sound designers should be educated and well versed in the medium to create high quality content that will pass muster with talent.
2. A new, file-based medium for the original UHDTV master may be needed, as tape cannot handle the increased resolution. IMF as defined by the SMPTE ST 2067 suite of documents is one possible choice that may be considered. Note that the carriage of immersive audio in IMF needs to be defined. See Appendix C for further details.
3. Uncompressed audio transport and bandwidth requirements need to be defined for moving audio in a production environment. Care must be taken to ensure the phase-alignment of samples for a sound-field is kept intact.
4. High quality immersive audio bandwidth requirements and realistic delivery payloads must be defined. In order to achieve that goal, baseband PCM, or very high quality audio codecs are likely to be used to transport immersive audio over broadcast infrastructure to maintain audio quality; any audio codec employed should meet the requirements for contribution/distribution specified in Annex 1 of Recommendation ITU-R BS.1548 (BS.1548), *User requirements for audio coding systems for digital broadcasting*.
5. New interfaces may be needed throughout the infrastructure, including production facilities, broadcast facilities and possibly in the home in order to handle immersive audio along with the higher bit rate video that will be required for UHDTV.
6. New audio playback solutions may be needed in the home to play immersive audio. Realistic rendering of immersive audio into a variety of playback systems is required.

(9) This study group recommends that SMPTE undertake additional work to study* extended requirements for audio *and infrastructure with specific consideration to the following areas:

- Standardize additional immersive audio formats to be used for UHDTV. Consideration should be given to audio standards created by other organizations, such as the ITU.
- Standardize a common file format to describe immersive audio to insure interoperability. Note that some of this work may already be underway in other SMPTE groups such asTC-25CSS and that the ITU-R is studying how to extend Recommendation ITU-R BR.1352 (BR.1352) - Broadcast WAV - to carry immersive audio.
- Standardize the carriage of uncompressed immersive audio over packetized real-time network interfaces, with attention to the technical issues of maintaining the phase relationships between the coincident digital samples in a given sound-field.

- Standardize audio characteristics for audibly lossless compression. This may reference Recommendation ITU-R BS.1116-1 (BS.1116-1), and other current standards. Note that this does not define the codecs themselves, only the required audio characteristics.

Summary of Recommendations

(1) This study group recommends that further work be undertaken to ensure that the employed UHDTV1 colorimetry is signaled in the interface.
(2) This study group recommends no change be made with regards to the conventional non-constant luminance parameters defined by ST 2036-1.
(3) This study group recommends that SMPTE undertake further work to study the issues and requirements for color space conversion to and from UHDTV color space and legacy Color space. This study should also consider the requirements to standardize colorist metadata
(4) This study group recommends that further work be undertaken to consider the implications of converting between 1/1.001 and the integer frame rate of 120Hz.
(5) This study group recommends no change be made to the UHDTV1 frame rates supported by ST 2036-1.
(6) This study group recommends that further work be undertaken to develop real-time streaming media interface standards in support of UHDTV1 image formats and payloads up to 120 fps.
(7) This study group recommends that SMPTE undertake work to define specific mezzanine image compression profiles and bit streams that can be mapped to the SDI interface.
(8) This study group recommends that SMPTE continue to work on standardization for the carriage of uncompressed UHDTV1 image streams over packetized real-time network interfaces.
(9) This study group recommends that SMPTE undertakes work to study extended audio requirements and infrastructure with specific consideration to the following areas:

- Standardize additional immersive audio formats to be used for UHDTV. Consideration should be given to audio standards created by other organizations, such as the ITU.
- Standardize a common file format to describe immersive audio to insure interoperability. Note that some of this work may already be underway in other SMPTE groups such asTC-25CSS and that the ITU-R is studying how to extend Recommendation ITU-R BR.1352 (BR.1352) - Broadcast WAV - to carry immersive audio.
- Standardize the carriage of uncompressed immersive audio over packetized real-time network interfaces, with attention to the technical issues of maintaining the phase relationships between the coincident digital samples in a given sound-field.
- Standardize audio characteristics for audibly lossless compression. This may reference Recommendation ITU-R BS.1116-1 (BS.1116-1), and other current standards. Note that this does not define the codecs themselves, only the required audio characteristics.

Glossary

UHDTV1: The 3840x2160 pixels -image format described in SMPTE ST 2036-1. Sometimes shortened to “UHD-1”.

UHDTV2: The 7680x4320 pixels image format described in SMPTE ST 2036-1. Sometimes shortened to "UHD-2".

"4k": A term used to describe images of 4096x2160 pixels although sometimes applied to UHDTV1 images of 3840x2160 pixels. ***This term should not be used when referring to UHDTV1.***

"8k": A casual term for UHDTV2 images of 7680x4320 pixels. ***This term should not be used when referring to UHDTV2.***

"Quad-HD": A casual term sometimes meaning images of 3840x2160 pixels using BT.709 color space. ***Use of this term should be avoided.***

Digital Cinema: This refers to the suite of standards produced by SMPTE 21DC (the SMPTE ST 428, ST 429, ST 430, ST 431, ST 432, and ST 433 suites along with the ST 2048 suite). Sometimes termed "D-Cinema." The image formats and workflows documented in these document suites are optimized for theatrical presentation and not television reproduction.

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Annex A - UHDTV - Constant Luminance considerations

While the ITU-R UHDTV Recommendation BT.2020 allows for both constant luminance and Non Constant luminance coding, the SMPTE UHDTV standard ST 2036-1 allows for only non-constant luminance coding.

Based upon conclusions reached by the ITU-R in their Report BT.2246, and various comparisons between the two coding schemes, SMPTE concluded that for production and post-production applications there was no practical benefit to be gained by allowing two coding schemes, technically they are equivalent.

There are potential system impacts in using constant luminance coding, with associated costs. Some work is reported in Report BT.2246, which considers the technical issues in detail.

Annex B - UHDTV – Audio Considerations

ORIGINAL UHDTV MASTERS

Audio in a UHDTV original master should be uncompressed with a sample rate of 48K or 96K at 24 bit (as specified in ST 2036-2) or higher resolution. IMF (Interoperable Master Format) could be utilized as the mastering format for UHDTV content. Note that the IMF application for UHDTV would fall under ST 2067-21 or ST 2067-30. The audio characteristics, specifications and audio labeling as defined in IMF documents ST 2067-2 and ST 2067-8 should be followed. It is noted that the carriage of immersive audio in IMF has yet to be defined.

CARRIAGE AND DELIVERY

In order to achieve high interoperability, standards for the carriage and delivery of immersive audio are critical. While there are various industry efforts underway, including BWF (Broadcast Wave Format), revisions in EBU and ITU-R, there is currently no standardized common file format for the carriage and delivery of immersive audio. TC-25CSS is currently engaged in studying this topic for cinema. The use of "audio objects" to convey the location of audio in a sound-field is a key component, and may form the basis of a common audio file format for feeding the distribution infrastructure to the home. In addition, object-based systems may provide greater flexibility for home listeners to adjust portions of the audio (such as voice levels) to assist with hearing issues.

AUDIO COMPRESSION

For high bandwidth distribution applications, the chosen audio compression ideally should be "mathematically lossless". Examples of mathematically lossless 5.1/7.1 audio compression are DTS Master Audio and Dolby True-HD, both of which are capable of carrying immersive audio objects. MPEG-4 ALS, and FLAC are also possibilities with some modification, and have open source implementations.

If it is not possible to use mathematically lossless codecs, it is recommended that the chosen compression format be "audibly lossless". Audibly lossless refers to audio compression that is psycho acoustically transparent and unable to be reliably differentiated by expert listeners when compared with the original uncompressed audio after a number of concatenated encode/decode cycles. Emission codecs at low-to-medium bitrates are typically quite lossy and not considered audibly lossless and therefore are not recommended in high bandwidth distribution applications. Examples include AC-3, DTS express, MP3 and AAC.

Where lossy codecs are required for consumer delivery of UHDTV, it is recommended that the compression format meet the requirements for emission specified in Annex 2 of Recommendation ITU-R BS.1548-2 (BS.1548-2).

Where lossy codecs are required in an UHDTV broadcast infrastructure, it is recommended that the chosen compression format meet the requirements for contribution/distribution specified in Annex 1 of BS.1548-2.

SPEAKERS AND SOUND REPRODUCTION CONSIDERATIONS

While it is unlikely that most home environments will allow for a number of additional speakers to reproduce immersive sound, other methods are available or have been proposed; for example, a Loudspeaker Array Frame attached around the TV screen, the addition of height speakers above the TV screen, or a sound bar system located below and/or above the TV screen.

"Audio Rendering" is a process that utilizes DSP modeling to reproduce a given audio format through multiple types of audio playback systems. The playback systems may utilize technologies such as Wave Field Synthesis (WFS) and binaural audio, among others. Rendering technology is a significant topic being discussed in the MPEG-H 3D audio project. It is possible that the reproduction of immersive audio in the home will depend heavily on audio rendering to be able to deliver the experience to a plethora of different playback systems, including headphones.

The use of a common audio file format combined with fixed or movable audio objects as noted above is key to providing a common input to deliver codecs and to allow audio rendering to be widely usable.

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Annex C - UHDTV Color Space Conversion

As previously discussed (see section 2.2.1), the UHDTV color gamut is significantly larger than legacy color spaces. UHDTV workflows and devices that solely support the UHDTV color space should be able to support an equivalent level of color interoperability and accuracy as BT.709 workflows and devices do today. However, it is envisioned that the industry will experience a long transition period when moving to the extended UHDTV color space for production and post-production. Color conversion to legacy BT.709 and Recommendation BT.601 color spaces to comply with legacy workflows will be required. The challenge in color space conversion therefore lies with mixed workflows and devices, where a device somewhere in the distribution chain receives UHDTV color space data and outputs BT.709 color space data, or maybe vice versa. Unless proper care is taken in color space conversion, material that takes advantage of the extended UHDTV gamut will look worse on a BT.709 display than material that originated in the BT.709 color space.

The key observation is that a **simplistic** color conversion **will** degrade the image quality to below the quality of a BT.709 original. **Techniques that are adequate for conversion between the BT.601 and BT.709 color spaces today are not usable for conversion between UHDTV and BT.709.**

Gamut mapping is NOT trivial. There is no automated method that always gives an acceptable result. Every known automated method works poorly for some images, usually for high-key and low-key scenes. Thus, grading Digital Cinema to BT.709 is always a manual scene-by-scene operation; select the mapping that is best for the scene at hand. For example, the Blu-Ray version of a movie is manually color graded scene-by-scene, and gamut mapped differently than the digital cinema movie master. Additionally, a colorist may use different gamut maps to subjectively optimize for interesting parts of the image, while de-emphasizing other parts, making the map a creative element in the story.

Varying Sensor and Monitor Responses

Different camera sensor technologies and display technologies from different vendors and for different price points offer widely varying color responses and gamuts. Attempts to match a particular color space standard are always an approximation. Much of the originating process (cameras and animation) is driven by the artistic choices of the manufacturers, cinematographers and colorists as they adapt their different technologies and content into standardized workflows.

Nevertheless, all of these differences have to converge at some point in order to interoperate with different content providers' and broadcasters' workflows, which is the point of standards in the first place.

BT.2020 to Legacy Conversion

It is envisioned that the industry will experience a long transition period when moving to BT.2020 UHDTV color space for production and post-production. Color conversion to legacy BT.709 and BT.601 color spaces to comply with legacy workflows will be required.

The conversion from BT.2020 to BT.709 needs to preserve the color details in saturated BT.2020 colors. It is NOT trivial to convert the colors that are outside of the BT.709 gamut to legal BT.709 colors. As stated above, this requires gamut mapping.

Applying the gamut mapping from BT.2020 to BT.709 could be an immediate operation, resulting in a BT.709 stream, or a deferred operation where the gamut mapping operations are carried as colorist metadata in the BT.2020 stream to be applied where the plant needs to convert to a BT.709 format. The industry will require standardized formats for this colorist metadata.

Legacy to BT.2020 Conversion

Similarly, converting legacy material in BT.601 and BT.709 color spaces to the much wider gamut BT.2020 color space must reverse the process. However, by merely mapping the legacy image to the limits of the wider gamut, the colors will look oversaturated and cartoonish. If the legacy images are mapped to their legacy equivalent in the BT.2020 color space, then they will look about the same as on a legacy workflow, but then the colors in the legacy material will look muted when mixed in with the much more brilliant BT.2020 compliant images.

Gamut extension of the legacy images can help mitigate the impact of these transitions, but as with gamut mapping, gamut extensions are an inexact science, more of an art, using human manipulation via a colorist, heuristics and preprogrammed algorithms for specific situations. Developing esthetically acceptable solutions for automated workflows will be a major problem for some time to come.

Concatenated Conversions

As media might get converted back and forth between BT.2020 and BT.709, ideally the conversion to BT.2020 should be the inverse of the conversion to BT.709. If it is not, then after multiple generations of conversions back and forth between the two color spaces, the image colors will drift further and further away from the original with each generation, causing saturated colors to change, most likely de-saturate and change luminance in each cycle. However, if the conversion to BT.2020 is the exact inverse of the conversion to BT.709, then saturated original BT.709 colors could appear extremely garish when converted to BT.2020, but at least they will not shift over multiple conversion cycles. This is a dilemma that may need to be addressed within the industry, including SMPTE and other standards organizations.

Annex D – Support for additional frame rates

Research into higher frames rate support for UHDTV systems is in progress principally to ensure that the dynamic resolution of UHDTV matches (or remains in proportion to), that of the static resolution.

For example, during camera pans to follow the action at sports events, static portion of the scene change between sharp (when stationary) and smeared (when panning). The implied constraint requiring a reduction of the pan rate is not always practical in live coverage, but in practice compromises such as camera shuttering and deliberate softening of the images (or a reduction in aperture correction) can help reduce the problem. Regardless of this, simple mathematics shows that motion of the camera or of objects within the scene at speeds higher than three pixels per field/frame eliminates all of the additional detail gained by the use of high definition, in the direction of motion. These problems will be compounded by increases in the spatial resolution of UHDTV.

A very simplistic approach would be to say that, if 50 fields per second is sufficient for Standard Definition (and this is a “big if”) then 150 fps is required for 1920x1080 HDTV and 300 fps for UHDTV1. But this is not the whole story.

The frame rate of 120 fps specified in ST 2036-1 is intended as a single worldwide high frame rate for UHDTV1. It implies equal pain in the conversion to and from the commonly used frame/field rates of 50 and 59.94 fps. The implications of this, and its long-term advantages (of simplification and potential cost savings for both standards and equipment) as compared to retaining the present split between the 50 and 59.94 worlds, is an area in need of further study, particularly in the area of standards/frame-rate conversion, and lighting flicker.

NHK’s work[6] has showed that 80 frames per second (fps) is sufficient to prevent flicker (and sample-and-hold displays in any case prevent flicker), and something over 100 fps is required for the fusion of trackable motion.

Thus 120 fps is designed to:

1. Exceed the threshold for visibility of flicker on intended screen size and brightness,
2. Exceed the threshold for the human visual system’s ability to track motion; such as to make a sequence of discrete images appear as a continuously moving entity.

The third requirement considered by NHK was to ensure that movement is not blurred. Dr. Sugawara’s work indicated that a shutter opening of 1/320 second was required to adequately freeze motion, independent of image resolution.

[6] Sugawara, M., 2011. *Psychophisical Requirements for Higher Frame Rates in Future Television.* DCS 2011, SMPTE Conference at NAB Show, Las Vegas, April 2011.

There are other aspects relating to image presentation and frame rate that go beyond the above three factors. Firstly, a short shutter (such as 1/320 second) with a higher frame rate (such as 120 fps) has three implications:

- It does not prevent aliasing of repeating structures (the wagon wheels going backwards effect),
- It does not prevent the impression of juddering in non-tracked motion (where there is more than one motion in the composition, where there is rotational motion, or where there is scaling of image components),
- There are implications for noise performance, due to a short shutter opening relative to the frame period.

All of these three factors would be mitigated by a frame rate of 300 fps, although further study is required to quantify the importance of these factors. This frame rate also has the virtue of easy conversion to 50 and 60 fps (but still retains the 1/1.001 issue).

Editing points might be in frame multiples. So edit points for 120 fps might be every 4 frames (i.e. as though editing material) or every 5 frames (as 24 fps). This issue needs to be considered. This also has implications for time-code representation.

Storage clearly increases with higher frame rates, although mezzanine compression may be an important enabling technology.

The increased noise in each frame, as a consequence of a shorter frame exposure time, is a potential challenge for coding techniques, although an increase from 50/60 to 120 fps is not hugely significant in this respect. The visibility of noise to the human visual system presented at higher frame rates reduces with increasing frame rates. Whether this will exactly counteract the increase due to the shorter capture time is not yet understood, and so is a known area for more work.

The extent to which higher frame rates are relatively easily handled within a file-based production flow should be an enabling technology for the practical implementation of what are presently unconventional frame rates. However, given that the main application of higher frame rates is likely to be live events (sport, etc.), real-time signal chains must be considered.

Annex E Critical Viewing Environment

For critical viewing, it is generally considered necessary to keep the worst-case viewing angle at less than 45 degrees away from perpendicular to the display. This is independent of display technology. At angles greater than 45 degrees, geometric distortion and light falloff become issues.

In a typical grading suite the colorist is centered on the display, with seating for one creative on either side. The widths of the seats are typically about .67 meters (about 26 inches) for such suites. Seat width turns out to be the controlling factor in selection of the display size.

Looking at the table below, we can see that for a 120" display, the worst-case viewing angle is 41.63 degrees. However, it may not be practical to use this large a display. Based on the numbers, it appears that 90" is the minimum display size if the primary viewer is in line with the horizontal center of the display.

Dimensions in meters unless otherwise specified						
screen diagonal	screen width	screen height	distance to center viewer	width of viewer **w**	side viewer normal to far edge of screen	worst-case viewing angle **a** (degrees)
120"	2.66	1.50	2.25	0.67	2.00	41.63
90"	2.00	1.13	1.69	0.67	1.67	44.70
60"	1.33	0.75	1.13	0.67	1.34	49.88

Annex F Bibliography

Recommendation ITU-R BT.2020 2012 Parameter values for ultra-high definition television systems for production and international programme exchange

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M. Nakamura, T. Nakatogawa, and K. Oyamada, "Development of Optical Interface for Full-Resolution Super Hi-Vision Production Systems", is available from ITE Tech, Rep., Vol. 33, No. 32, pp. 5-8, July 2009.

Recommendation ITU-R BT.601-7 (2011) Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios

Recommendation ITU-R BT.709-5 (2002) Parameter values for the HDTV standards for production and international programme exchange

Recommendation ITU-R BR.1352-3 (2007) File format for the exchange of audio programme materials with metadata on information technology media

Recommendation ITU-R BS.1116-1 (1997) Methods for the subjective assessment of small impairments in audio systems including multichannel sound systems

Recommendation ITU-R BT.601-7 2011 Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios

Recommendation ITU-R BT.709-5 2002 Parameter values for the HDTV standards for production and international programme exchange

Report ITU-R BT.2246-2 (2012) - The present state of ultra-high definition television

SMPTE ST 259:2008 SDTV Digital Signal/Data —Serial Digital Interface

SMPTE ST 292-1:2012 1.5 Gb/s Signal/Data Serial Interface

SMPTE ST 297:2006 Serial Digital Fiber Transmission System for SMPTE 259M, SMPTE 344M, SMPTE 292 and SMPTE 424M Signals

SMPTE ST 377-4:2012 MXF Multichannel Audio Labeling Framework

SMPTE ST 424:2012 3 Gb/s Signal/Data Serial Interface

SMPTE ST 425-1:2011 Source Image Format and Ancillary Data Mapping for the 3 Gb/s Serial Interface

SMPTE ST 425-2:2012 Source Image Format and Ancillary Data Mapping for Stereoscopic Image Formats on a Single-Link 3 Gb/s Serial Interface

SMPTE ST 425-4:2012 Dual 3 Gb/s Serial Digital Interface for Stereoscopic Image Transport

SMPTE ST 428-1:2006 D-Cinema Distribution Master — Image Characteristics

SMPTE ST 435-1:2012 10 Gb/s Serial Signal/Data Interface — Part 1: Basic Stream Derivation

SMPTE ST 435-2;2012 10 Gb/s Serial Signal/Data Interface — Part 2: 10.6921 Gb/s Stream — Basic Stream Data Mapping

SMPTE ST 435-3:2012 10 Gb/s Serial Signal/Data Interface — Part 3: 10.6921 Gb/s Optical Fiber Interface

SMPTE ST 2022-6:2012 Transport of High Bit Rate Media Signals over IP Networks (HBRMT)

SMPTE ST 2036-1:2013 Ultra High Definition Television – Image Parameter Values for Program Production

SMPTE ST 2036-2:2012 Ultra High Definition Television — Audio Characteristics and Audio Channel Mapping for Program Production

SMPTE ST 2036-3:2012 Ultra High Definition Television — Mapping into Single-link or Multi-link 10 Gb/s Serial Signal/Data Interface

SMPTE ST 2048-1:2011 2048 × 1080 and 4096 × 2160 Digital Cinematography Production Image Formats FS/709

SMPTE ST 2048-2:2011 2048 × 1080 Digital Cinematography Production Image FS/709 Formatting for Serial Digital Interface

SMPTE ST 2048-3:2012 4096×2160 Digital Cinematography Production Image Formats FS/709 — Mapping into Multi-link 10 Gb/s Serial Signal/Data Interface

SMPTE ST 2063:2012 Stereoscopic 3D Full Resolution Contribution Link Based on MPEG-2 TS

SMPTE ST-2066:2012 Disparity Map Representation for Stereoscopic 3D

SMPTE ST-2068:2013 Stereoscopic 3D Frame Compatible Packing and Signaling for HDTV

The following documents are currently in development within SMPTE and may not be publically available at time of this writing.

Proposed SMPTE ST 425-3:20xx Image Format and Ancillary Data Mapping for the Dual Link 3 Gb/s Serial Interface

Proposed SMPTE ST 425-5:20xx Image Format and Ancillary Data Mapping for the Quad Link 3 Gb/s Serial Interface

Proposed ST 425-6:20xx Quad 3 Gb/s Serial Digital Interface for Stereoscopic Image Transport

Proposed ST 2062-1:20xx 25 Gb/s Serial Signal/Data Interface — Part 1: Source Image Format and Data Mapping
Proposed ST 2062-2:20xx 25 Gb/s Serial Signal/Data Interface —Part 2: 25.79851 Gb/s Optical Fiber Interface
Proposed SMPTE ST-2076-1:20xx Stereoscopic 3D (S3D) Production Timing and Synchronization - Camera Systems
Proposed SMPTE ST-2076-2:20xx Stereoscopic 3D (S3D) Production Timing and Synchronization – Live Production Systems
Proposed SMPTE ST 2076-3:20xx Stereoscopic 3D (S3D) Production Timing and Synchronization - Physical Layer for Video Transport
Proposed SMPTE EG 2076-4:20xx Stereoscopic 3D (S3D) Production Timing and Synchronization - Physical Layer and System Guidance