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**Video and Audio Interoperability in
Today's 4K UHD Home Entertainment Environment**

UHD Alliance Interoperability Technical White Paper

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Table of Contents

What is Interoperability?

Interoperability is defined in Wikipedia as 'a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, at present or in the future, in either implementation or access, without any restrictions.'[1] The 4K UHD home entertainment ecosystem and environment consists of 4K UHD displays, source devices (e.g. UHD Blu-ray players, set-top boxes, media receivers, gaming consoles, etc.), A/V Receivers and sound bars. Proper interoperability within this ecosystem would effectively mean that all devices would seamlessly connect together and result in a proper image and proper sound.

What Should Happen?

At the base of every 4K UHD home entertainment environment is a 4K UHD display. Within this environment there may also be one or more source devices such as a Blu-ray Disc player, cable box, gaming console, media player (e.g. Apple TV 4K, Fire TV 4K, Chromecast, Roku Streaming Stick +, etc.) a multi-channel A/V receiver or sound bar. When connecting these devices together, the result should be a proper picture appearing on the display and proper audio heard from the output device whether it is the TV speakers, the sound bar or the speakers connected to a A/V receiver.

What is a Proper Picture?

4K UHD content provides for many great capabilities which can include:

High Dynamic Range (HDR)
Provides greater range of contrast compared to HD content resulting in greater clarity and more detail in the shadows and highlights.[2]

The Lego Batman Movie © 2017 Warner Bros. Entertainment Inc. TM & © DC Comics © 2017 The LEGO Group
"The Lego Batman Movie now available on 4K Ultra HD Blu-ray"
HDR / SDR

Wide Color Gamut (WCG)

Provides support for the BT.2020 color gamut which covers approximately 75% of the visible color gamut compared to the BT.709 (HD) color gamut which covers approximately 39% of the visible color gamut.

The Meg © 2018 Warner Bros. Entertainment Inc.
"The Meg now available on 4K Ultra HD Blu-ray"
BT.2020 / BT.709

Increased Bit-Depth (10-bit)

Allows presentation of more than 1 billion colors compared to 8-bit which supports approximately 16 million colors.

The Lego Batman Movie © 2017 Warner Bros. Entertainment Inc. TM & © DC Comics © 2017 The LEGO Group
"The Lego Batman Movie now available on 4K Ultra HD Blu-ray"
8-bit / 10-bit

A proper picture would result in the display presenting an image with the HDR, WCG and bit-depth capabilities enabled. However, just because an image can be seen on the screen, it doesn't mean that picture is correct.

What is Proper Audio?

At the core of every home entertainment system there is at a minimum the TV speakers. Beyond this there are many different audio options. One option is that of a sound bar, which can either be stand-alone, or the sound bar can include subwoofers and satellite speakers. Beyond sound bars there are A/V receivers. The A/V receivers can be configured for multi-channel audio, including speaker configurations of 2.1, 3.1, 5.1, 7.1, as well as the newer immersive audio configurations which can be configured for 5.1.2, 5.1.4, 7.1.2 or 7.1.4.

TV with built-in speakers

TV with soundbar

TV in Multi-channel environment *(courtesy of Dolby Laboratories)*

The audio implemented in content is typically configured for some level of multi-channel support. Proper audio playback would consist of the audio being output to the maximum number of channels it supports up to the maximum capabilities of the home entertainment system. So if the audio in the content is configured for 5.1 and a home theater system can support 7.1.4, the audio should be output for 5.1. If the home theater only supports 3.1 then the audio output should be 3.1. However, just because sound can be heard, it doesn't mean that the audio is output correctly.

UHD Alliance Interoperability Studies

The UHD Alliance created an Interoperability Working Group (IWG) within the organization to investigate interoperability issues. During the investigations, many issues were identified – both with video and audio playback. As part of the interoperability testing, specific test methodologies were developed to further identify the cause of the video and audio interoperability issues. During all the testing procedures, the devices were always reset to their factory default in order to experience what a consumer out-of-the-box experience would be.

Detailed information on the testing methodology for video can be found in Annex A, and for audio in Annex B. Additionally, Annex C provides an overview of the kinds and number of devices that were included in the testing efforts to date.

What Should Not Happen?

A consumer should not have an experience that is lesser than the maximum capabilities their home entertainment system can support based on the maximum capabilities of the content they are playing.

What Is Happening? What Are The Issues?

Unfortunately, interoperability issues exist today which result in improper video playback and/or improper audio output. Some of the issues the UHD Alliance has encountered include the following:

VIDEO ISSUES

Black Screen
This is a very obvious issue. A source device is connected to a 4K UHD display which results in a black screen on the display. Some may think there is an issue with the TV or the source device or the cable. It could be caused by one or more of these issues or just a simple setting issue.

No HDR (SDR)
HDR is one of the great capabilities of 4K UHD content. Most displays will indicate 'HDR' in some manner when HDR content is detected. However, interoperability issues could result in the HDR capabilities of the display not being activated, making the content appear flat, dark or having other issues which may not be apparent to the viewer. The bigger issue here is that the viewer will see a picture on the screen and think everything is working fine. The reality is that the picture that appears on the display is lacking the HDR features and capabilities and not displaying the content to its full capability or potential. The full creative intent that the 4K UHD display is capable of is not achieved .

Banding

4K UHD content is capable of supporting at least 10-bit color and over 1 billion colors. This feature allows for smooth gradients within color transitions (e.g. light blue sky to dark blue sky) or brightness and darkness transitions (e.g. moonlight to dark sky). Banding issues reduce the amount of color being displayed and create bands within colors or bands within light to dark transitions which should not appear.

Godzilla: King of the Monsters © 2019 Legendary and Warner Bros. Entertainment Inc. GODZILLA TM & © Toho Co. Ltd.
"Godzilla: King of the Monsters now available on 4K Ultra HD Blu-ray"
Banding Example

Lower Resolution

It goes without saying that 4K UHD is a higher resolution (3840x2160) than HD (1920x1080). In some interoperability scenarios, 4K UHD content is displayed in HD resolution.

Fast & Furious Presents: Hobbs & Shaw © 2019 Universal Studios.
4K Resolution / HD Resolution

AUDIO ISSUES

No Audio

One would expect to hear audio when playing content. In some interoperability scenarios, however, no audio is output by the audio output device (e.g. sound bar or A/V receiver).

Multi-channel Audio Output as 2-channel

As most of the audio embedded in content provides multi-channel support, it would be expected that if a home entertainment system supports more than 2-channel audio, multi-channel audio output would be the result. In some interoperability scenarios, playback of multi-channel audio in a multi-channel home entertainment system resulted in only 2-channel stereo output.

Reduced Channel Output

The test environment supported multi-channel immersive audio up to 7.1.4. In some interoperability scenarios, playback of 7.1.4 audio resulted in reduced channel outputs of 7.1 or even 5.1.

ARC/eARC Not Outputting Audio

ARC/eARC provides the ability to send the audio signal from the TV out to an audio output device (e.g. sound bar, A/V receiver). In some interoperability scenarios, either the TV is not sending audio over ARC/eARC to the output device or the output device is not able to process the signal from the TV. Both situations can result in no audio.

Lip Sync

When audio and video sync are off by 3 or more frames, it can become very apparent to the viewer. In some interoperability scenarios lip sync issues of 3 or more frames were identified.

Why are Interoperability Issues Occurring?

Today's home entertainment technology has many more capabilities than the technologies of the past. HDMI cables are used to connect devices and carry the video, audio, and auxiliary data between the various devices. But with the capabilities provided by the HDMI technology there also come challenges. There are different communication bandwidth/speeds, different versions of cables, legacy system restrictions, factory defaults and the devices don't always speak the same language or have the same interpretation for signals or data, thus resulting in a 'miscommunication' or 'interoperability issue.' Below we discuss some of the technologies and features associated with interoperability challenges.

HDMI

With the introduction of HDMI there is the ease and simplicity of having a single cable connecting a source device, and possibly repeater device (e.g. A/V Receiver) to a display. However, there are different versions of HDMI, and some HDMI cables may only support specific versions of HDMI. For purposes of this Technical White Paper, we'll discuss the difference between HDMI 1.4, 2.0 and 2.1.

HDMI 1.4

- Provides for 4K UHD resolution up to 30 Hz
- Provides for HDCP 1.4
- Color gamut of BT.709
- Bandwidth up to 300MHz
- 8-bit color depth
- 8 audio channels
- Added ARC support for audio

HDMI 2.0

- Provides for 4K UHD resolution up to 60 Hz
- Provides for HDCP 2.2
- Color gamut of BT.2020
- Bandwidth up to 600MHz
- 12-bit color depth
- 32 audio channels
- HDR

HDMI 2.0a

- HDR with static metadata

HDMI 2.1

- Provides for 4K UHD resolution up to 120 Hz
- Provides for 8K UHD resolution up to 60 Hz
- Added eARC support for audio
- HDR with dynamic metadata

| Capability	HDMI 1.4	HDMI 2.0	HDMI 2.0a	HDMI 2.1
4K 30Hz	X	X	X	X
4K 60Hz		X	X	X
4K 120Hz				X
8K 60Hz				X
HDR		X	X	X
HDR (static metadata)			X	X
HDR (dynamic metadata				X
BT.709	X	X	X	X
BT.2020		X	X	X
300MHz Bandwidth	X	X	X	X
600MHz Bandwidth		X	X	X
8-bit color depth	X	X	X	X
12-bit color depth		X	X	X
8 audio channels	X	X	X	X
32 audio channels		X	X	X
ARC	X	X	X	X
eARC				X
HDCP 1.4	X	X	X	X
HDCP 2.2		X	X	X

HDMI Capabilities

HDMI Inputs

Most displays have 2 or more HDMI inputs. However, not all HDMI inputs on a display are equal. Some of the displays do not support HDMI 2.x on all HDMI inputs or do not support 600 MHz bandwidth. What this means is that if you plug a source device that requires HDMI 2.x into an HDMI input that doesn't support HDMI 2.x, you will not be able to take advantage of all of the features supported by the source device, despite the fact that your display device may generally support those features – the input becomes the bottleneck. The TV may require you to only use specific HDMI inputs for your HDMI 2.x source device. However the labeling on a TV is not always clear to the consumer when specific inputs are required for supporting 600 MHz bandwidth.

HDMI Input Setting / Factory Defaults

To address issues with legacy devices connecting to displays supporting HDMI 2.x, some displays have the HDMI inputs set to a default setting which only supports 300MHz (legacy HDMI 1.4 bandwidth). This can result in HDR content appearing in SDR, color being limited to 8-bit, resolution being reduced to HD or other issues. Correcting this would require the setting for the HDMI input to be configured to support 600MHz (HDMI 2.x bandwidth). While some devices have implemented automatic device detection features, which switches this setting automatically, other devices that don't have automatic detection features will require this change in the HDMI input setting to be done manually by the user. To make matters worse this feature is labeled differently for each manufacturer making it more difficult for the user.
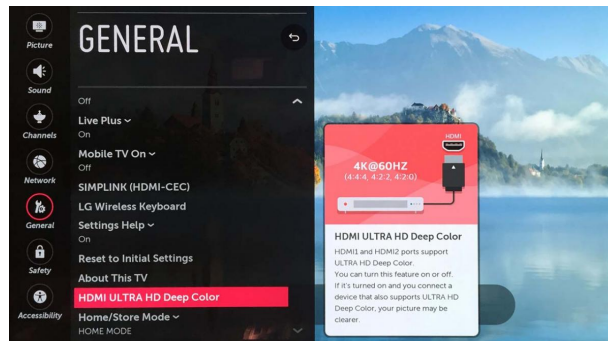
DISPLAY SETUP SCREEN
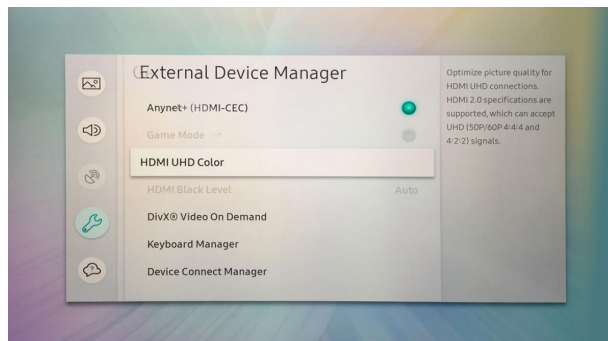
DISPLAY SETUP SCREEN
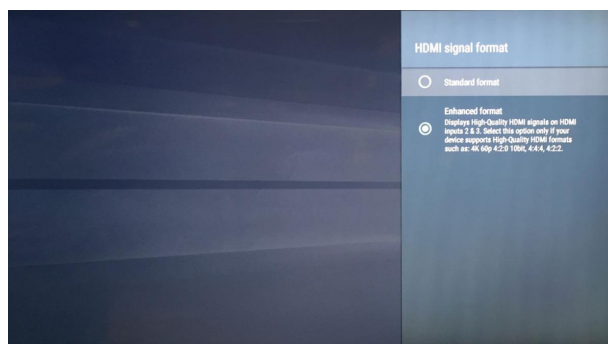
DISPLAY SETUP SCREEN

(More details available at https://www.experienceuhd.com/hdr-set-up)

EDID (Extended Display Identification Data)

All displays support EDID via their HDMI implementation. The EDID information includes details on the supported color gamut and HDR capabilities of a display. This data is sent from the display to the source device so that the source device knows what the capabilities of the display are and can send an appropriate signal. One of the identified interoperability issues was that some displays are configured with incorrect or incomplete EDID information. This can result in the source device sending a BT.709 signal rather than a BT.2020 signal. Or it can result in the source device sending an SDR signal rather than an HDR signal, even though the display itself is capable of displaying the better signal.

HDMI Cables

HDMI cables need to be matched for the signal they need to carry. In the early days of HDMI, cables included version numbers on them to indicate what version of HDMI they supported. HDMI cables no longer include the HDMI version numbers they support. Instead, HDMI cables now include the following descriptors:

- Standard
- High Speed
- High Speed with Ethernet
- Premium High Speed
- Ultra-High Speed

For HD resolution, a Standard HDMI cable is sufficient. For 4K UHD content, at minimum a Premium High Speed HDMI cable is required. Using a Standard HDMI cable can result in a black screen or an image with reduced capabilities (e.g. SDR, 8-bit, etc.).

Capability	Standard	High Speed	Premium High Speed	Ultra High Speed
4K 30Hz		X	X	X
4K 60Hz			X	X
4K 120Hz				X
8K 60Hz			X	X
8K 120Hz				X
18 Gbit/s			X	X
48 Gbit/s				X

Legacy Equipment

In some scenarios, legacy equipment (e.g. HD source device) connected to a 4K UHD display can result in a black screen. This can occur due to mismatched HDMI input settings, incorrect EDID information or other factors.

CODEC Licensing/Support

Content typically includes 1 or more of the 3 audio codecs listed below for the audio program:

- PCM
- Dolby
- DTS

Some displays may not license/support all of the audio codecs. In these situations, the resulting audio over ARC/eARC would be stereo rather than multi-channel audio. Although this situation would seem to be incorrect to the consumer, because the display is not licensed to decode the audio, the display may output the audio over ARC/eARC in PCM stereo. The consumer may believe there is a technical issue but in reality this would be a codec licensing/support issue.

Device/Application Capabilities and Limitations

4K source devices are considered to be devices that can output 4K UHD content to a 4K UHD display. However, some source devices may include platform apps for 4K services but not output in 4K UHD for the 4K UHD services. Instead the apps would output in HD resolution even though the source device is a 4K UHD device and the platform supports 4K UHD. One example is YouTube, where the platform contains 4K UHD HDR content which can be output in 4K UHD HDR. However, when running the YouTube app on some 4K UHD media players, the output to the display is in HD rather than 4K UHD. Based on this a consumer may assume that something is wrong when they select an app/service on their 4K UHD device that supports 4K UHD, but they are only seeing an HD output.

How Can Things Improve? What Needs To Change?

There are many opportunities for improving these issues. Some of them include:

- Better consumer OOB (out of box) configuration/experience.
  - Configuring devices in such a way that their default settings are implemented to provide the best level of compatibility with other devices.
- Smarter devices
  - Implement additional auto detection capabilities to allow devices to better communicate, identify and connect to each other.
- Getting started guides w/common issues.
  - Provide consumers with solutions for common issues by means of updated documentation, FAQs, etc. included with the product and on product websites.
- Manufacturer guidelines/best practices
  - Manufacturers working together to resolve issues that have been identified by the UHD Alliance and other organizations. Use this information to develop best practices for the device out of box settings to help improve the consumer experience.

What Improvements Have Been Made Already?

As a result of the UHD Alliance interoperability testing, there have been many improvements including:

- More displays implementing auto detect functions resulting in HDMI inputs properly configured for 600MHz for 4K UHD devices
- The elimination of black screens
- Reduction of scenarios where 4K UHD content is output in SDR instead of HDR
- Reduction of scenarios where 4K UHD content is output in 8-bit instead of 10-bit
- Improved audio channel outputs via eARC

Statistics on reduction of video interoperability issues:

TEST PHASE	FAILED TESTS
Initial Test (2017)	53%
Last Test (2019)	26%
Improvement	104%

What's Next To Further Improve Interoperability?

The UHD Alliance has been working on interoperability for several years. While this effort began internally, it quickly expanded to other stakeholders in the 4K UHD ecosystem, and the UHD Alliance will continue its leadership role to help identify and address the interoperability issues that exist in the 4K UHD ecosystem. As part of this initiative, the UHD Alliance is committed to continue the following efforts:

- Continued UHD Alliance interoperability testing leveraging the Warner Bros. Media Lab
- Participating in interoperability events hosted by other groups and organizations (DTG, CTA, etc.)
- UHD Alliance Website section with suggested settings for specific devices
- Development of best practices for device manufacturers
- CEDIA collaboration (e.g. member seminars and events)
- Industry Education

The ultimate goal is for interoperability issues to no longer exist. Only through continued testing, investigation and collaboration with all of the stakeholders can this be achieved. The UHD Alliance is committed to being at the forefront of this investigation/endeavor and will not stop until it is resolved.

Footnotes:
[1] https://en.wikipedia.org/wiki/Interoperability
[2] https://www.experienceuhd.com/uhd-premium-features

ANNEXES

Annex A: VIDEO TEST PROCESS

STEP #	TEST DESCRIPTION
1	Perform a factory reset on both the source device and TV.
2	Verify that the devices tested have the latest commercially available firmware.
3	Connect an EDID Test Device to the TV HDMI input using a cable which has verified 18Gbps performance (High Speed Cable). (**NOTE**: TV may require using an input other Input 1 for full UHD support).
3a	Extract and record the EDID binary.
3b	Review and note EDID Colorimetry values.
3c	Review and note EDID HDR STATIC METADATA values.
4	Connect the source device HDMI output to the TV input HDMI 1 using a cable which has verified 18Gbps performance (High Speed Cable). (**NOTE**: if the TV indicates that an input other number 1 should be used for UHD, use that designated input(s)).
5	Insert a UHD Blu-ray disc containing 24fps content which has characteristics known by the tester into the player. It should be unambiguously possible to identify picture performance with respect to HDR, color gamut and color bit depth.
6	Play the main program of the disc and verify the following characteristics:
6a	The content is playing in HDR mode as indicated by the TV. The TV may indicate this automatically or it may be necessary to use a TV function to display the information. If HDR is not achieved, note accordingly.
6b	Verify the TV is playing the content in BT.2020 color gamut. If BT.2020 is not achieved, note accordingly.
6c	Verify the picture does not exhibit 8-bit banding artifacts. If picture reproduced is 8-bit, note accordingly.
7	Replace the 24fps disc with a UHD Blu-ray disc containing 60fps content which has characteristics known by the tester. As with step 5, the disc characteristics should be easy to identify by the tester.
8	Repeat steps 6, 6a, 6b, 6c with the 60fps UHD Blu-ray disc.
9	Replace the UHD Blu-ray player with the next test source device (e.g. gaming console, media receiver, USB source, etc.,)
10	Select an appropriate application and content. As with step 5, the content characteristics should be easy to identify by the tester.
11	Repeat steps 6, 6a, 6b, 6c which each source device, application and content.

Annex B: AUDIO TEST PROCESS

DEVICE	TEST#	TEST DESCRIPTION
DIRECT RENDER	1	Perform a factory reset on both the source device and TV.
	2	Verify that the devices tested have the latest commercially available firmware.
	3	Set the UHD Blu-ray player to output 'bitstream' audio.
	4	Connect the source device HDMI output to the TV input HDMI 1 using a cable which has verified 18Gbps performance (High Speed Cable). (**NOTE**: TV may require using an input other Input 1 for full UHD support) (**NOTE2**: ARC/eARC input should not be used)
	5	Insert audio test content disc which has 7.1.4 channel characteristics for designated audio codec into the UHD Blu-ray player.
	6	Play the appropriate program of the disc and verify the following characteristics:
	6a	All channels contained in the content are rendered by the TVs internal speakers, and there are no audible negative audio artifacts.
	6b	Confirm that there are no missing channels in the audio presentation (i.e., all the material contained in the 7.1.4 channels of the source material are audible through one or a suitable combination of the TV speakers).
	6c	Confirm levels for each channel are equal and no individual channel sounds louder or lower than other channels.
A/V RECEIVER	7	Connect AVR (configured and connected to 7.1.4 speaker configuration) to HDMI input on TV that supports ARC/eARC.
	7a	Connect mixer (or other test device that can identify individual signals to each of the 12 channels) to each analog output of the AVR.
	8	Play the appropriate program of the disc and verify the following characteristics:
	8a	All channels contained in the content are rendered by the AVR's connected speakers and there are no audible negative audio artifacts.
	8b	Confirm that each channel in the audio presentation is rendered to the proper channel (i.e., all the material contained in the 7.1.4 channels of the source material are audible through the appropriate output speaker of the AVR and are visible in the appropriate channel of the mixer).
	8c	Confirm levels for each channel are equal and no individual channel sounds louder or lower than other channels.
SOUND BAR	9	Connect Sound bar to HDMI input on TV that supports ARC/eARC.
	10	Play the appropriate program of the disc and verify the following characteristics:
	10a	All channels contained in the test content are rendered by the sound bar and there are no audible negative audio artifacts.
	10b	Confirm that each channel in the audio presentation is rendered by the sound bar appropriately.
	10c	Confirm levels for each channel are equal and no individual channel sounds louder or lower than other channels.

Annex C: Tools & Devices Used

Below is a table of the test devices and test tools used throughout the interoperability testing:

Tested Equipment:		
4K UHD Displays	21	Various manufacturers
UHD Blu-ray Players	10	Various manufacturers
Media Receivers	4	Various manufacturers
PCs	1	
Gaming Consoles	2	Various manufacturers (1 also included in UHD Blu-ray Players)
A/V Receivers	5	Various manufacturers
Sound Bars	3	Various manufacturers
Reference Equipment:		
UHD Blu-ray Player	Oppo UDP-203	
A/V Receiver	Denon AVR-X8500H	
EDID Capture Device	HD Fury	
Mixer	Allen & Heath ICE 16	
Test Content:		
24p Content	Various UHD Blu-ray Discs	
60p Content	Sony Pictures 60p Test Disc	
Dolby Audio Test Content	Dolby 2018 Blu-ray Demo Disc – 7.1.4 channel callout track	
DTS Audio Test Content	DTS 2019 UHD Blu-ray Demo Disc – 7.1.4 channel callout track	