# THE COMPLETE UHD GUIDEBOOK – A REFERENCE TOOL FOR NEXT-GENERATION VIDEO

DOLBY

harmonic

tdg the diffusion group

# UHD – THE FUTURE IS NOW

Ultra-High-Definition ('Ultra-HD' or 'UHD') represents the next big step in the evolution of video recording, processing, and display technology. It is the logical successor to HD and offers marked improvements over current video technologies, chief among them a *four-fold* increase in resolution from 1080p.

While improved resolution is a key benefit, UHD enhances other important video and audio characteristics including:

- Higher frame rates (resulting in smoother motion);
- Higher dynamic range (resulting in brighter brights and striking contrast);
- Greater color depth (resulting in a much greater range of colors than supported by the current HD standard); and
- Dramatically improved audio (resulting in a much richer video viewing experience).

But its benefits come at a cost. When uncompressed, UHD delivery can demand *four times* the bandwidth of regular HD, meaning significantly greater storage and transport costs. Add to this the expense of systems upgrades to support UHD and the value proposition can seem a bit cloudy.

As well, the arrival of UHD has introduced complexity and fragmentation into an ecosystem whose members have yet to agree upon a common standard as to what 'Ultra-HD' actually *is*. This lack of consensus has created uncertainty throughout the TV and video value chain, both in terms of interoperability and consumer perception.

Despite these challenges, widespread diffusion of UHD is all but certain. Hardware is firmly slotted as a natural replacement for aging HD sets, with UHD TVs accounting for a growing share of both retail floor space and OEM marketing budgets. Those in the business of TV and video are coming to terms with this reality, and UHD has become a key component of strategic planning. Content creators and distributors, in particular, are searching for ways to balance the benefits of providing dramatically-improved viewing experiences with the costs of building and supporting a UHD system.

This eBook provides a realistic appraisal of the future of UHD and the challenges and opportunities that creatives, network operators, and service providers will encounter as the TV ecosystem transitions from HD to UHD. Within you will find:

- A detailed discussion of UHD video and audio solutions, including an examination of key technical issues that must be resolved in order for UHD to reach the mainstream;
- An analysis of the market context in which UHD will mature, discussing supply- and demand-side drivers and inhibitors; and
- Strategic recommendations for industry stakeholders.

Additionally, we hope that this publication serves as your 'desktop' reference guide to all that is UHD; a resource to which you turn when seeking to clarify UHD concepts and terminology.

# CONTENTS



DOLBY harmonic

produced by tdg the diffusion group

## The UHD Ecosystem: An Abstract

Ultra-HD is a video ecosystem whose development is occurring in real time. Once in place, it will ultimately cover UHD from acquisition to display.

For live transmissions, content is captured and either processed for future distribution, or directly passed to a service provider or broadcaster for final distribution. For video-on-demand (VOD), content can be either pushed to a PVR STB (push VOD) or simply carousel transmitted as a broadcast channel (nVOD).

Since most connected TVs support HTTP streams, live content should be transmitted as unicast IP data to TVs that feature UHD decoding capability. Non-linear content is transcoded in either single bitrate for delivery over QoS-enabled IP networks (cable or telcos) or in multiple bitrates for delivery across the open Internet (over-the-top or OTT). A content delivery network (CDN) will carry these packaged VOD assets and deliver them to home receivers.

On the receiving side, there are two options: Ultra-HD can be decoded by the television (as is the case for all newer UHD sets), or decoded by operator set-top boxes connected to the television via HDMI (the latter being the long-term option, especially for TV service providers).

**Exhibit 1 – The UHD Ecosystem**

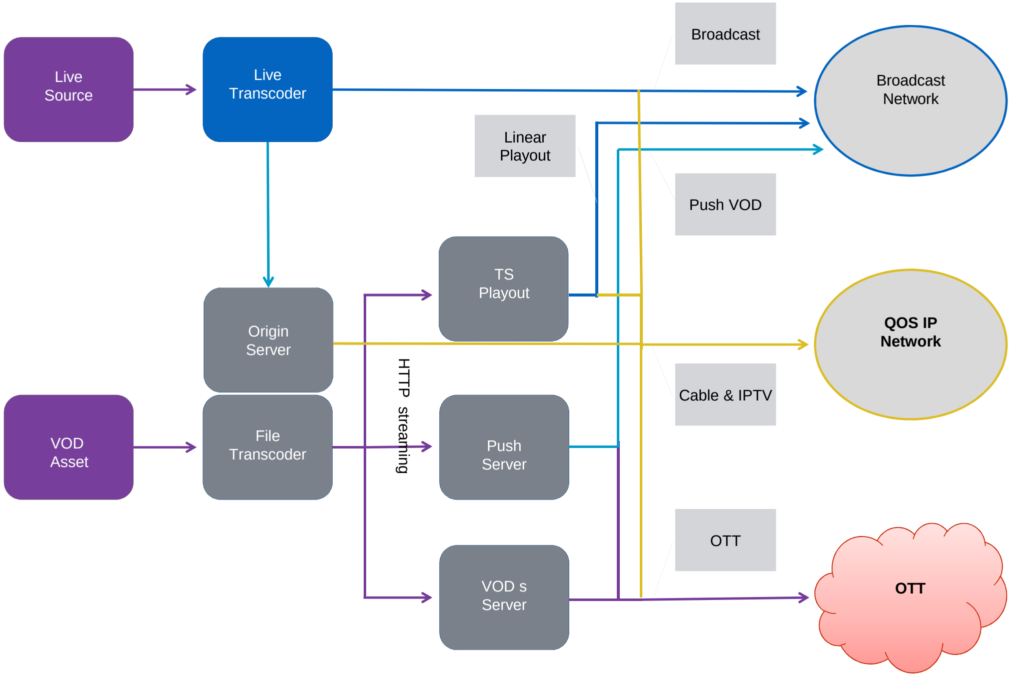
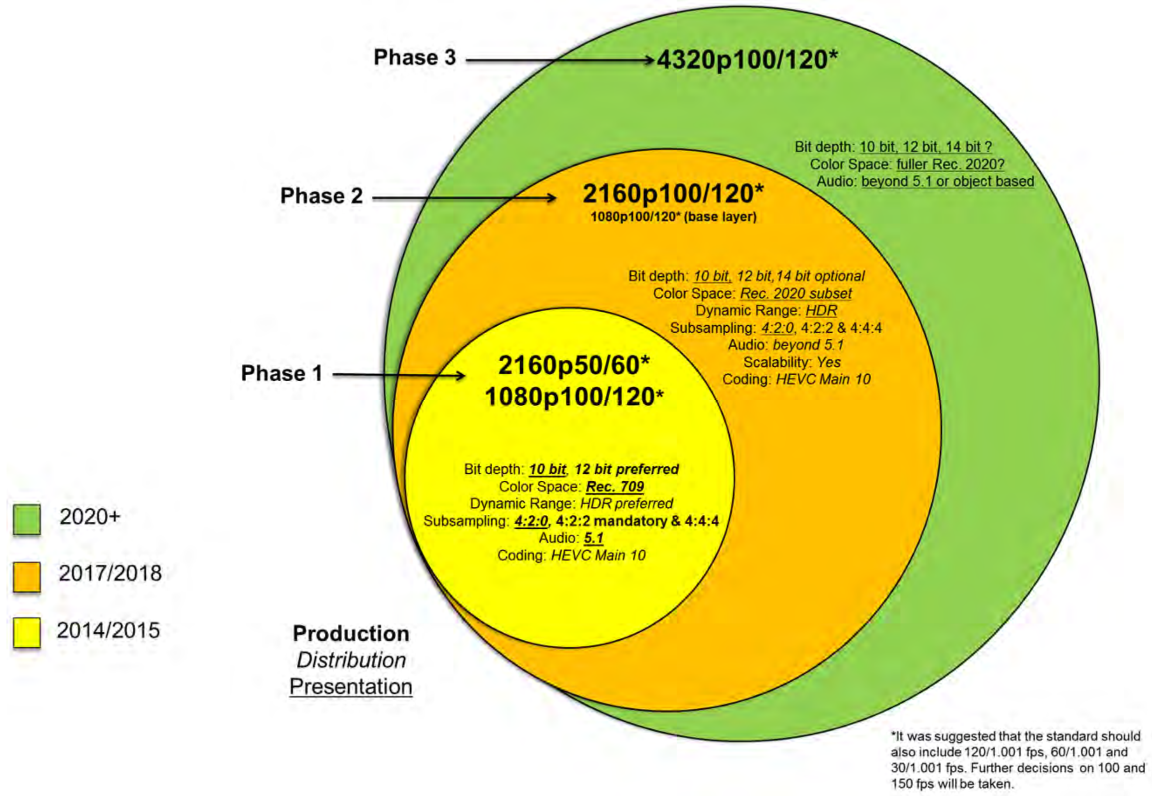


**Exhibit 2 – UHD Implementation Phases**




# UHD Implementation

To date the conversation around UHD has focused primarily on its increased spatial resolution (more pixels). Fortunately that has changed and it is now now widely acknowledged that UHD offers a slew of additional benefits, including increased frame rates (faster pixels) and dynamic range (more colorful pixels), and delivers truly immersive audio, all of which have a dramatic impact on viewer satisfaction.

The latest UHD specification has added provisions for HDR, colorimetry, and advanced audio. As shown in Exhibit 2, the DVB UHD specification stipulates improvements for each element in Phase 2 and Phase 3. Though the implementation of HDR has yet to be completed, the industry is converging on a HDR standard that will ultimately be incorporated into the DVB UHD specification.

Next we turn to the specific enhancements that UHD provides, beginning with dramatically enhanced resolution.

# Improved Resolutions – UHD vs. 4K

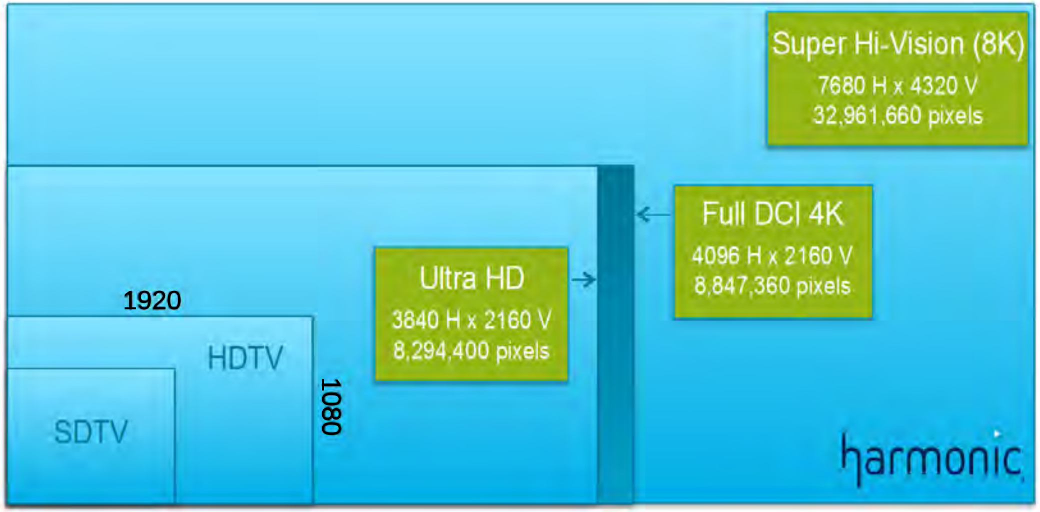
Ultra-HD is a near-4K format where the horizontal and vertical resolutions have been specifically chosen as integer multiples of 1920 X 1080 (HD resolution). Yet UHD and 4K differ in a great many respects, most notably the style of shooting and the act of picture scanning. Despite the differences, TV manufacturers, broadcasters, and social media mavens are now using the terms ‘4K’ and ‘UHD’ interchangeably.

Put simply, 4K is a *professional production and cinema standard*, while UHD is a *consumer display and broadcast standard*. The term ‘4K’ comes by way of the Digital Cinema Initiatives (DCI), a consortium of motion picture studios that standardized a specification for the production and digital projection of 4K film. Ultra-HD, on the other hand, is a standard penned by the Society of Motion Picture and Television Engineers (SMPTE) and comprised of a set of documents (SMPTE ST 2036) describing UHD Television (UHDTV).

Note that cinema (film) is a *progressive* format where a complete scene is scanned, whereas television is predominantly *interlaced*, meaning the scene is split into two fields that sacrifice spatial resolution in favor of temporal resolution. Moreover, digital cinema is typically displayed at 24 frames-per-second (fps) progressive, while television’s interlaced (crudely) reduces spatial content while retaining temporal resolution to better support fast-moving content.

The good news for both 4K and UHD is that the current lineup of home and personal displays is a respectable match for the requirements of digital cinema content, especially when delivered as video-on-demand (VOD).

**Exhibit 3 – Television Resolutions: Past, Present, and Future**




That said, today’s screens have a difficult time matching the vivid color portrayal and high dynamic range associated with cinema. It is no surprise that the first UHD services to be deployed were broadband UHD VOD services from Netflix, Amazon, and Sony; services that uniquely matched available technology with high-value cinematic content originally shot as 4K .

Though each company refers to its solutions as ‘UHD 4K,’ they are in fact UHD, not 4K. This is just one instance of how the two terms are used improperly, most often for marketing purposes.[1]

## Increased Frame Rate

Another important enhancement of UHD is a marked increase in frame rate. This is best illustrated when viewing live TV sports, where the presence of high-motion content frequently exceeds that typical in cinematic content. As it stands, current interfacing via the latest generation of HDMI can deliver 50/60-fps progressive content (the best possible), though this is not typically deployed for HD broadcast applications (meaning HD remains an interlace domain). The move towards larger screen formats is spurring sports rights owners and broadcasters alike to question whether merely matching the current HD frame rate is adequate. Trial shooting of European soccer has highlighted the need for the upper frame rate to be increased to 100/120-fps, which results in roughly 30% greater bandwidth consumption and, consequently, significantly greater carriage expenses.

Before CES 2015, frame rates beyond that supported by HDMI were viewed with skepticism, principally because no widely deployed consumer interface existed to support the (significant) additional data rate. Two technologies featured at CES 2015 promised to address this shortcoming.

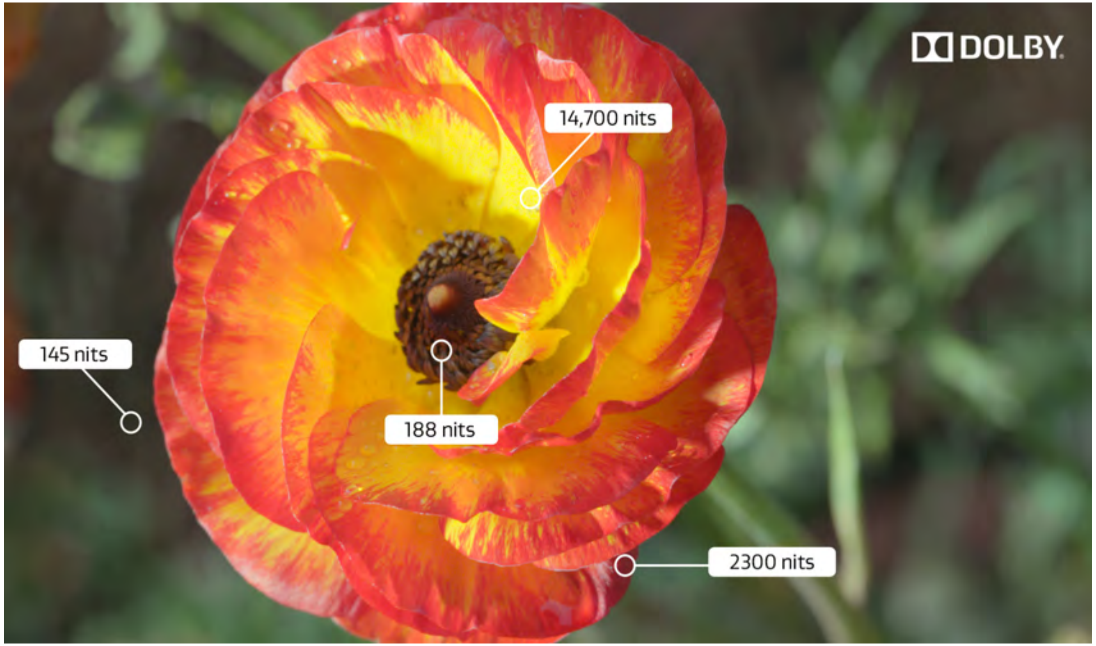
- Display Screen Compression (DSC), which utilizes 3:1 compression to cope with the additional bandwidth needed to support higher frame rates. This is used primarily with Display Port (a common graphics display interface) but with obvious applications to other closely-related interfaces; and
- Display Link, which utilizes dynamic compression to match the payload with the available bandwidth in order to enable 4K delivery over USB 3.0 and Wi-Fi.

## Enhanced Colorimetry and Dynamic Range

Both consumers and content creators have responded positively to the idea of enhancing color and dynamic range, meaning demand for solutions supporting these features will be strong. Subsequently, content providers, pay-TV operators, and display manufacturers are now delivering HDR using Dolby® Vision. Ultra-HD screens using Dolby Vision will be in market well in advance of the planned availability of services supporting Phase 2 of the UHD specification.

It should be noted that the implementation roadmap for UHD has yet to achieve worldwide agreement. No doubt there will be differences in how the specifics of this road map will be implemented.

**Exhibit 4 – Example of Nit Variance in a Single Image**




## *The History of Colorimetry and HDR*

The natural world has a much broader range of color and brightness than current broadcast, Blu-ray, and cinema systems can support. As illustrated in Exhibit 4, brightness ranges from 145 nits for the background, to 14,700 nits for the yellow part of the petal. (A *nit* is a unit used to measure brightness and is equivalent to a candela per square meter.)

Current television and Blu-ray standards limit maximum brightness to 100 nits and minimum brightness to 0.117 nits, while also restricting the gamut of colors that can be displayed. These and other limitations of modern HDTV standards are a legacy of cathode ray tube (CRT) technologies that originated during the first half of the twentieth century.

To understand the deficiencies associated with color portrayal on 4K and UHD screens, one must understand the respective capabilities of each display media.

**Exhibit 5 – CIE 1931 XYZ**

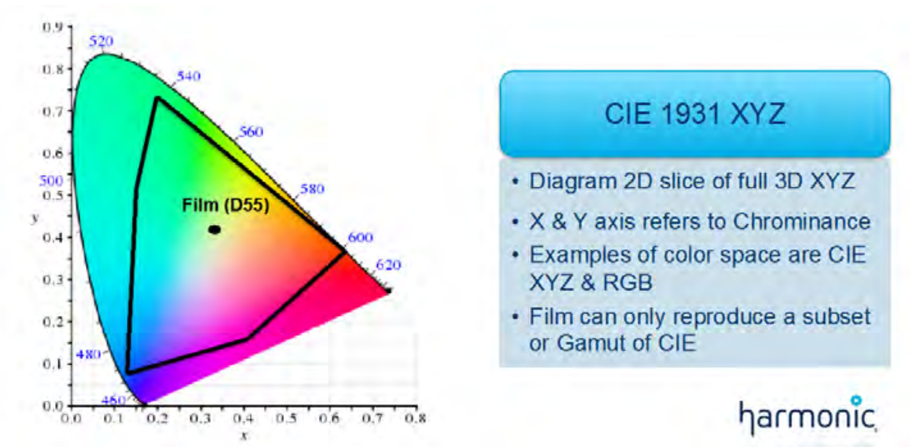
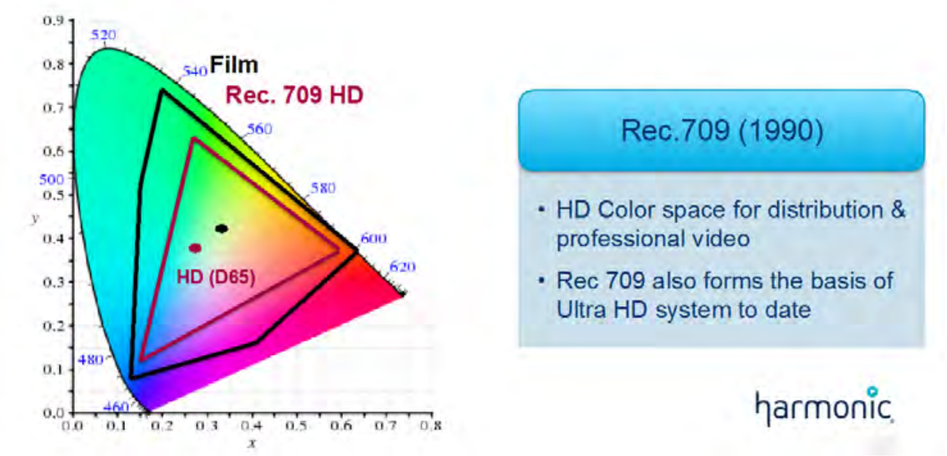



**Exhibit 6 – Rec. 709**



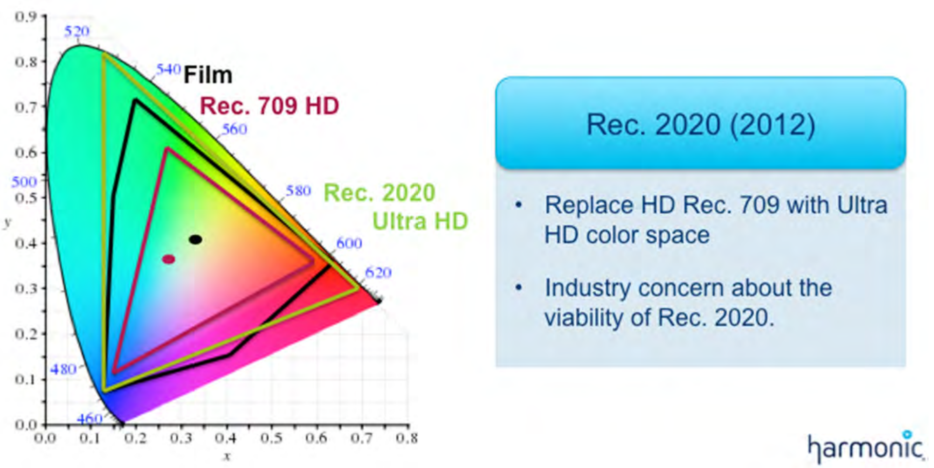

The exhibit above shows the entire visible color spectrum as defined by CIE 1931, a reference mapping of color space to the human eye essential for the management of display color. No screen is capable of displaying the full visible spectrum defined by CIE 1931, only specific gamuts.

By comparison, the HD color space (part of Rec. 709, the standard behind the HD format, first approved in the early 1990s) is much smaller than that of film.

As a result of these limitations, the International Telecommunications Union adopted a new display standard based on recent advances in UHD (Rec. 2020, first introduced in 2012). This provides a much wider color gamut for both UHD and 4K applications, as Rec. 2020 uses lasers to generate pixel colors rather than white light shown through rare-earth phosphors.

Rec. 2020 identifies D65 as the white point of its color space, located at [0.3127, 0.3290], the same specification as used in Rec. 709. The difference between the two standards is, put simply, the available gamut and depth of bits support (Rec. 709 is limited to 8-bit depth, whereas Rec. 2020 supports 10- and 12-bit depth).

**Exhibit 7 – UHD Rec. 2020 Color Space**




From a colorimetry perspective, all seems relatively straightforward: develop screens with Rec. 2020 capabilities. The problem with this approach, however, is that few screen technologies exist that can fill the existing 9-color space of Rec. 70, let alone Rec. 2020. At CES 2015, screens were exhibited that achieved 85% coverage of Rec. 2020 color space. Prior to that time, the vast majority of screens, both HD and UHD, were based on Rec. 709 HD color space. This may at first seem bizarre, but behind every display technology is some form of color mapping.

It is important to note that the UHDTV color gamut is significantly larger than those of both HDTV and SDTV. For example, the UHDTV color gamut volume (in XYZ space) is twice that of HDTVs. Workflows and devices that support the UHDTV color space can achieve a level of color interoperability and accuracy equal to today's HDTV workflows and devices. That said, the process of upgrading to the extended UHDTV color space for production and post-production will not happen all at once but rather incrementally, meaning color conversion to and from legacy HDTV and SDTV color spaces will be required.

If native color conversions were performed between the UHDTV and HDTV/SDTV color gamuts. The conversion algorithm would the assume that the content filled the UHDTV color gamut and color volume would be reduced appropriately to create an HDTV or SDTV version. (In principle, each display device could measure the content color gamut of an incoming signal and process the content suitably.) The content color gamut may vary according to on-the-scene artistic choices, which may result in unstable color conversion. This issue can be resolved by sending a metadata description of the color gamut of the images with the UHDTV content.

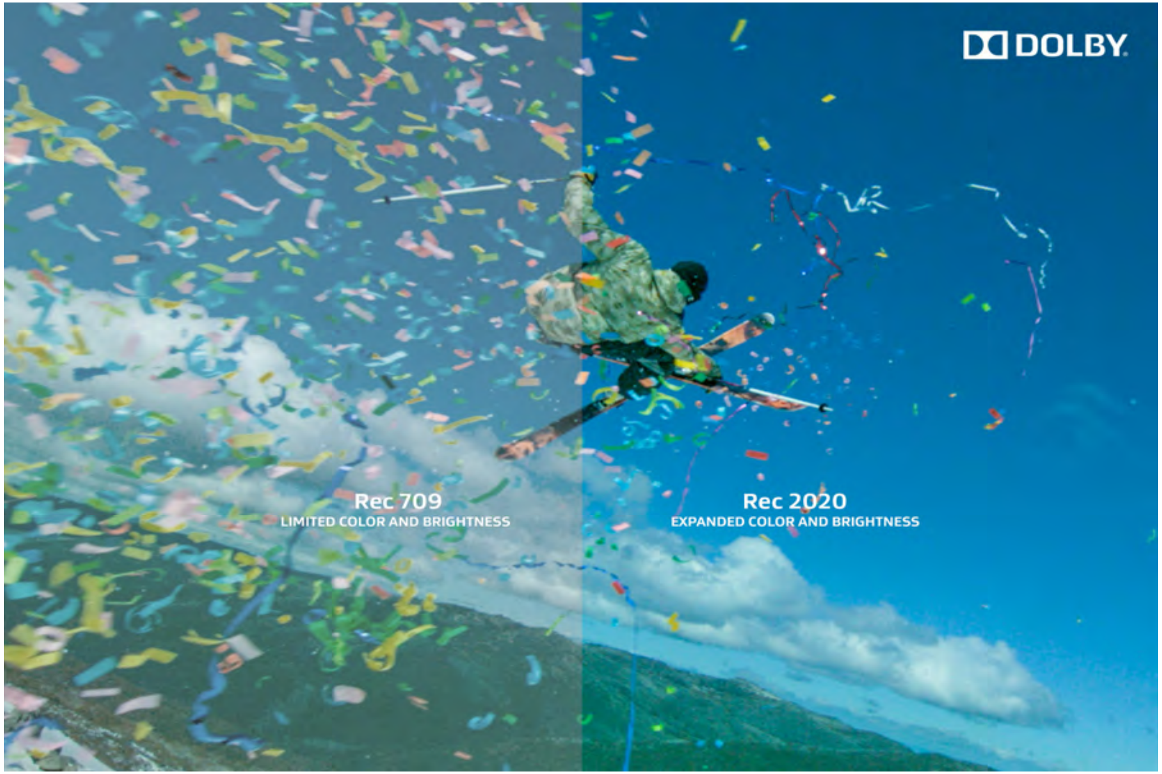
With Rec. 709's 8-bits per color, roughly 256 shades can be rendered (minus some margin at the extremes), which means Rec. 709 can deliver a maximum of 16.8 million colors (256 red x 256 green x 256 blue). As previously noted, Rec. 2020 stipulates 10- or 12-bit depth. With 10-bit color Rec. 2020, one can deliver 1.1 billion colors; at 12-bit, one can deliver 68.7 billion colors. In other words, Rec. 2020 can display a much larger color gamut than Rec. 709, rendering more realistic and vivid color as illustrated in the following picture.

But Rec. 2020 comes with its own set of challenges. For example, while it enables a much wider color gamut, it fails to consider the need for pixels with increased dynamic range and brightness. This is something that must be addressed as updates to the UHD standard are considered.

Keep in mind that a television display is an additive color system—red, green, or blue—meaning that the brightest pixel is white. The problem with restricting maximum brightness to 100-nits (as in broadcast and Blu-ray) is that the brighter the color, the whiter it becomes, and the more quickly it becomes less saturated. For instance, the brightest blue on a restricted-brightness display is a mere 7 nits, meaning that when viewing a blue sky on a UHDTV without HDR, the blue will never be as bright as it should be.

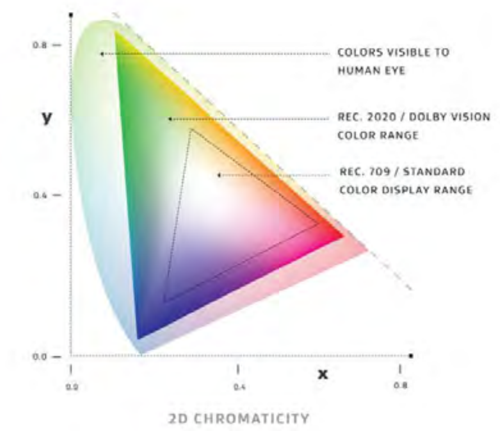
While the aforementioned gamuts display the colors available for standard brightness, they do not reflect the color saturation achieved as dynamic range is increased. To see this in reality, one must also examine color space as the brightness level is increased to the range of brightness (i.e., the color volume). The following figure showcases the increase in color volume associated with the expansion of both the color gamut and the dynamic range enabled by a system like Dolby Vision.

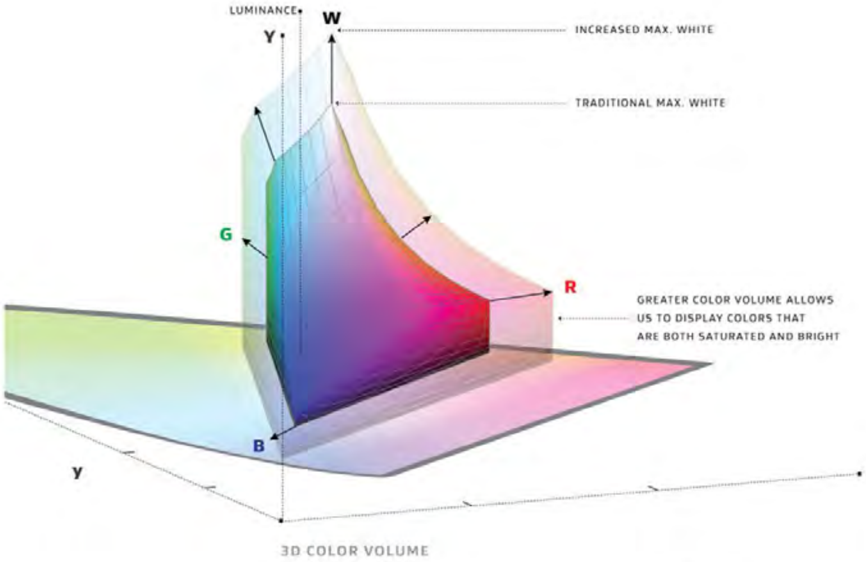
**Exhibit 8 – Rec. 709 vs. Rec. 2020: A Side-by-Side Comparison**



## Exhibit 8 – The Relationship between Color Volume, Gamut, and Dynamic Range

Moving beyond the limitations imposed by CRT and HD, content providers are now able to deliver much brighter brights, much darker darks, and more vivid colors that bring out greater dimension and detail, while delivering a wide range of incredibly lush and vivid colors. This enables the drama of intense light and colors, which complements the precision of UHD's increased resolution. In turn, the viewer enjoys a more compelling entertainment experience that lures them more fully into the story and increases their engagement with the content.



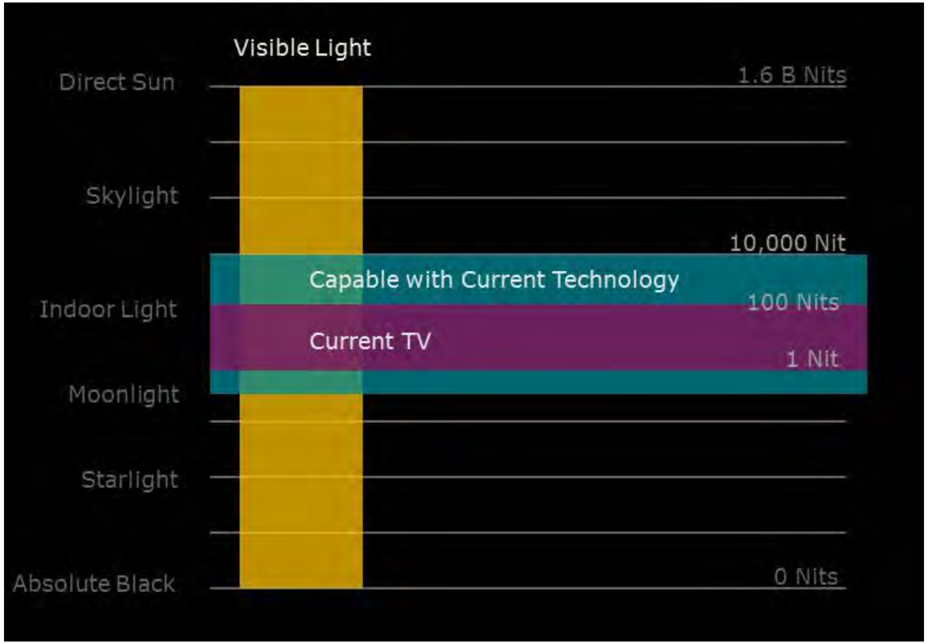




DOLBY

Tremendous potential exists for expanding the dynamic range, but just how much is needed? To determine these levels, Dolby's image research team conducted experiments to test what ordinary viewers preferred for black level, diffuse white level, and highlight level. When asked to pick an ideal range, 90% of viewers were satisfied with a system reproducing a range of 0-10,000-nits.

As mentioned earlier, Rec. 2020 offers an increased color gamut, but fails to consider the need for pixels with an increased dynamic range and brightness. This must be addressed as updates to the UHD standard are considered. Companies like Dolby have been looking at how best to extend simultaneously both the color gamut and the dynamic range. By increasing maximum brightness of today's monitors to 4,000 nits (and up to 10,000-nits in future displays), a content creator will have the range to represent a sky that is truly bright and saturated, making it appear more natural.

**Exhibit 9 – Comparison of Human Vision, and Televisions and HDR Displays**




### *Implementing HDR and Wide Color Gamut*

The maximum brightness for a movie or game is 100 nits. Yet modern TVs often have 300-500 nits, so TV manufacturers 'stretch' the brightness of the output, which often distorts the images. Because each manufacturer stretches brightness differently, every viewer will experience a movie, TV show, or game in a different (and frequently unpredictable) way.

It is worth noting that, given current displays, implementing anything beyond Rec. 709 colors is unnecessary. In order for viewers to enjoy Rec. 2020 UHD, the entire television system, from camera to display, must support the spec's enhanced dynamic ranges and color spaces. Without such support, every TV program would look different on different television displays.

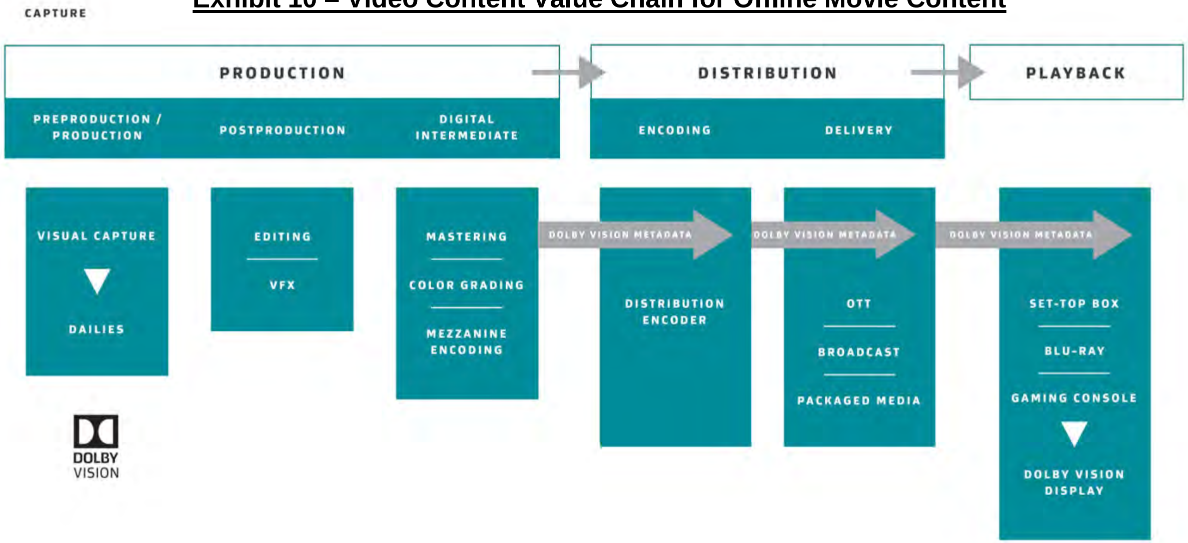
While the television display should deliver content in the way content creators intend it be viewed, in many ways the television itself extends or widens color gamuts of a picture by manipulating the image supplied by a Blu-ray player or operator set-top box. This can result in oversaturated colors, which can be very difficult for the display to overcome. The goal of HDR delivery should be to give the director and colorist (or the game programmer or the lighting and effects designer) the tools needed to represent accurately the vibrant colors, bright highlights, and detailed shadows that help draw the viewer into the scene.

### *HDR Content Creation*

While it is imperative that operators employ HDR solutions, current broadcast and Blu-ray standards have made this all but impossible. That is, until recently: new advancements across the delivery chain mean the future looks much brighter (and definitely more colorful) than before.

Exhibit 12 illustrates the video content value chain for offline movie content, from the creator to the end user, and highlights the links that must be in alignment in order to support the optimal production, distribution, and playback of HDR content. While this content flow is presently limited to offline content, these same tools will be available in time for live broadcast productions. This is particularly likely given the arrival of the first HDR 3-chip broadcast cameras from Grass Valley, a company driving the innovation of live UHD production techniques.

**<u>Exhibit 10 – Video Content Value Chain for Offline Movie Content</u>**




When a movie is created, there is a point in the process during which the director, colorist, and others produce a *master*—an exclusive version of the film from which copies are produced and distributed. Studios then create multiple masters, each targeted to specific viewing contexts, and each with its own advantages and disadvantages. For example, movie theaters produce a wider array of colors than home televisions, so studios create a master with a wide color range but compromised brightness. On the other hand, since movie theaters cannot achieve the same brightness as televisions, studios produce a separate master for televisions with compromised color but greater brightness.

Unfortunately, if the color gamut and dynamic range is not present in the original master, post processing can never recover them. Now that televisions are capable of delivering as much color as movie theaters—and even greater brightness—a new type of master is being created to leverage these capabilities, thus rendering the most impressive UHD content to date.

As well, for content to be displayed across a wide range of screens means that color mapping must be conveyed as metadata. For cinema, the variations in screen format are relatively limited. In the case of televisions, however, this is not the case, and each format requires a specific color space. Now that television viewing is a multi-screen phenomenon, legacy issues associated with color space and metadata have become increasingly difficult to address, especially within the tight manufacturing budgets associated with current television display production. For content creators, then, the question is the extent to which this requires new filming techniques or new equipment. Good news on this front: HDR does not require new filming techniques and in fact, enables a director to take full advantage of the technological innovations that define today's cameras.

Though the ability to create and deliver HDR content has been limited by a number of factors, particularly lagging camera technology and inadequate broadcast reference monitors, these issues are now being addressed and HDR broadcast content will soon be available for delivery. To address shortcomings in broadcast reference monitors, Dolby developed the Pulsar monitor, which features peak brightness of 4000 nits with a DCI-P3 color gamut, and a set of HDR plug-ins to commonly-used offline production suites that meet the needs of content creators. Using these tools, creatives can color-grade content to ensure the highest-fidelity mastering. Because the manufacturer and Dolby technicians carefully calibrate each Dolby Vision television, it is guaranteed to produce the best and most accurate representation of the creator's intentions.

At CES 2015, a number of TV manufacturers featured prototype HDR TVs, meaning commercial launches will follow shortly. In fact, the next two years will see a number of screen manufacturers implementing HDR, with luminance performance on consumer screens expected to achieve 1500 nits based on technology viable within the tight cost constraints and stringent power consumption regulations that define the consumer display market.

## *Considerations for Creating and Transmitting HDR Content*

Optimally, the HDR workflow will be very similar to existing color-grading workflows for both cinema and broadcast. The goal is to preserve more of what the original camera captured and therefore limit creative trade-offs associated with the color-grading and mastering process. Working with an HDR reference monitor capable of up to 4,000-nits luminance, the grading process clearly reflects artistic intent within the HDR broadcast master, and permits creative teams to take full advantage of the dynamic range of the display to make the most-engaging imagery possible.

Having established different masters for different displays, the challenge for content creators shifts to determining how best to transmit and present this content to the viewer. To address this challenge, and based on the work of Dolby and others, a set of HDR delivery standards have been selected, the specifics of which are outlined below.

- The industry needs a *single production workflow* for both SDR and HDR content so the transition to UHD supports legacy HD televisions and HD network infrastructure.
- The solution must be *compatible with existing file-based and real-time infrastructures* to support not only cinematic content, but also live broadcast content.
- Matching the creative intent, the *highest-quality images must always be available* to the home viewer; and must take into account that, whether for professional or consumer applications, *image qualities will improve as display technology evolves*.
- The transmission system must be *backwards compatible* with today's BT.709 or BT.2020 systems and should be *independent of any spatial resolution, color gamut, or frame rate*.
- New HDR TVs must be *capable of mapping the transmitted HDR images to the TV display's native color volume* (defined by the display's black level, peak white level, color temperature, and color primaries), thereby remaining as true as possible to the original creative intent within the confines of the display's capabilities.
- To ensure that HDR content can be delivered consistently, it should be *supported by leading standards organizations*, including the Blu-ray Disc™ Association, UltraViolet™/DECE, and the SCSA.
- The HDR transmission system should *use industry standard codecs* and be designed to *take full advantage of existing HEVC and AVC codecs*, while offering bitrate efficient transmission.
- The solution should be capable of being *tuned for each target display device*, based on device brightness, color gamut, and other characteristics.
- The capabilities of the UHD TVs will evolve over time as new technologies such as quantum dots allow wider color primaries and brighter displays. Systems should thus combine a television's inherent display characteristics and the HDR solution as metadata to *allow any form of display to adapt optimally to incoming HDR images* in order to match the display's characteristics.

### *Backward Compatibility – The Million-Dollar Question*

Given the fact that UHD TVs that do not support HDR are currently in retail stores and in a growing number of living rooms, there will be a very large installed base of incompatible UHD TVs when full UHD services with HDR commence (which will begin in the next few years). The question on the minds of many is how best to address this challenge.

There are different ways to tackle this problem, especially in the broadcast case. First, one could create a backward-compatible, layered stream where the base layer works with the installed base of non-HDR (or Standard Dynamic Range SDR UHD televisions, what DVB refers to as 'Phase 1 implementation'). Legacy UHD televisions would only take the base layer and provide an SDR experience, while new UHD sets with HDR capabilities would decode both base and advanced layers and provide a full UHD experience. Dolby Vision supports this scheme and is currently being deployed for VOD applications.

Another approach is to acknowledge that operators will deploy set-top boxes to ease the transition between Phase 1 (SDR) and Phase 2 (HDR). In that scenario, a legacy Phase 1 STB will have to decode a Phase 2 signal (single layer) and output either SDR uncompressed to a Phase 1 TV or a direct Phase 2 signal (compressed or uncompressed) to Phase 2 TV. In this scenario, the operator (service provider or broadcaster) will only broadcast a Phase 2 signal. This means all STBs in field are capable of interpreting Phase 2 HDR signals and providing outputs according to the capability of downstream connected devices.

**Exhibit 11 – Options to Address HDR Backwards Compatibility Issues**

| Backward Compatibility scheme | Stream | Type | Decoder | Display |
|---|---|---|---|---|
| Stream | Base layer | Phase 1* | Phase1 | Phase 1 |
| | Advanced layer | Phase 2** | Phase 2 | Phase 2 |
| Set-top box | Single layer | Phase 2** | Phase 2 with HDR->SDR*** | Phase 1 |
| | | | Phase 2 | Phase 2 |

**SDR only ** HDR ***Requires SMPTE metadata*

Note that in some cases a decoder and display will be integrated in the UHD TV. Both scenarios are under evaluation by DVB and ATSC, with a specification expected soon.

In the case of OTT delivery, the situation should be less restrictive, as an operator could encode in both formats (Phase 1/SDR and Phase 2/HDR), although the costs of transcoding, storage, and CDN delivery could be prohibitive, meaning the broadcast mechanism might also well apply to OTT.

# Challenges Facing UHD Video

Ultra-HD production is demanding on a variety of fronts, including bandwidth, storage, and interface. This section discusses some other key technical challenges associated with these elements.

**Exhibit 12 – The UHD Cinematic/Offline Workflow**

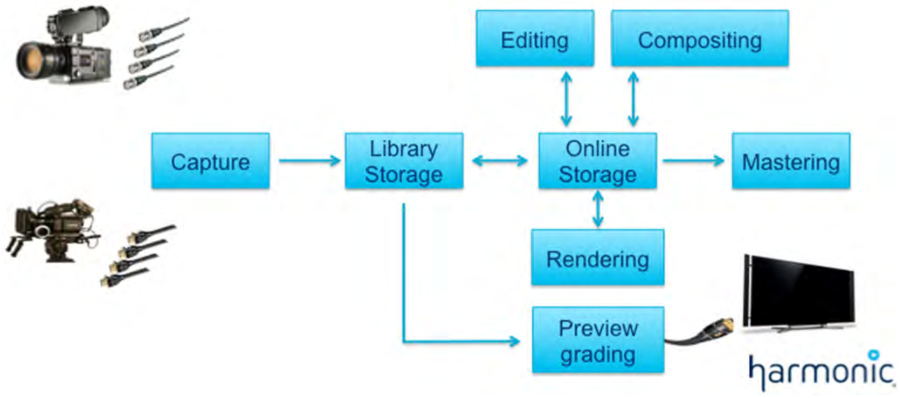
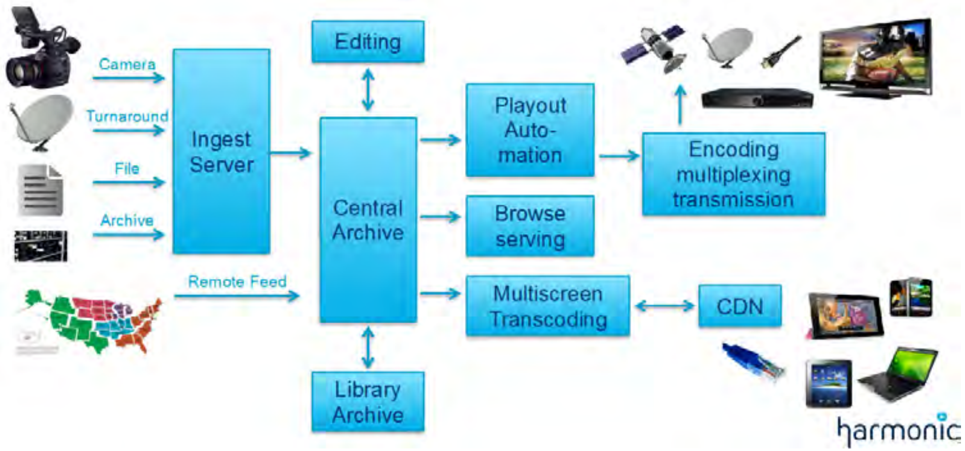



**Exhibit 13 – The UHD Live Workflow**




*UHD Workflows, Live and VOD*

As illustrated above, to obtain a file suitable for UHD VOD applications, a UHD cinematic workflow is used, which involves a relatively simple extension of the HD workflow. From a distribution perspective, however, delivering live UHD TV is undoubtedly more complex than delivering UHD VOD, due in large part to the complex nature of the ingest feeds, live production, playout, and display devices common in today's multi-screen ecosystem.

The fact that the industry only recently upgraded to HD and adjusted to the real-time bandwidth requirements of live HD TV explains why the majority of 4K deployments have to date been green-field VOD. Moving to live UHD is a far more challenging proposition.

### *UHD Delivery Architecture*

As previously discussed, OTT VOD efforts signaled the official introduction of UHD to the consumer market. During 2015, a number of operators and broadcasters will join Netflix, Amazon, and Sony to associate their brand with UHD VOD. The challenge will be providing sufficient fidelity to avoid awkward comparisons with up-scaled HD. (As will be discussed, very few users are now able to receive live linear UHD TV given existing broadband provisions.) While the ability to enjoy true UHD content may be the principle reason Early Adopters upgrade from HD, the key criteria will be whether the UHD viewing experience is sufficiently superior to existing HD services. In many cases this will be determined by the quality of the up-conversion technology behind the screen. A comparison of compression bit rates demonstrates how close a respectable 1080p HD signal can be, especially when compared to the equivalent UHD signal requiring double the bit rate.

This is not to decry the benefit of UHD, but rather to highlight the necessity of improving connection performance when live UHD streaming or broadcasting services are launched in mass.

**Exhibit 14 – Comparison of Compression Rates**

| | Compression / Bit Rate | | Resolution / Frame Rate | UHD Experience |
|---|---|---|---|---|
| HD Legacy | H.264 MPEG-4/AVC | 6 Mbps | 1920 *1080(i)*30fps | Poor Quality |
| TrueHD | H.264 MPEG-4/AVC | 8 Mbps | 1920 *1080(p)*60fps | Enhanced Quality |
| 4K | HEVC | 10 Mbps | 4096 *2160(p)*30fps | 4K Quality |
| Ultra HD1 | HEVC | 15 Mbps | 3840 *2160(p)*60fps | UHD Quality |
| Ultra HDx | HEVC | 20Mbps | 3840*2160(p)*120fps | Ultimate Quality |

As noted above, 4K movies require around 10-Mbps in order to deliver true 4K qualities, which benefit considerably from the low 24-fps frame rate that helps keep down the overall compressed bitrate. To achieve similar quality for UHD applications would require 15-Mbps for dramas and at least 20-Mbps for premium sports applications that endorse 100/120-fps. While these may appear frightening to those holding the purse strings for channel delivery, there is no doubt broadcasters regard the move to UHD as a strategic necessity, with satellite, cable, terrestrial, and broadband delivery all working toward the launch of live UHD capabilities.

**Exhibit 15 – Bitrate Required for UHD Delivery Reference**

| Reference | Specification | Additional Bitrate vs. Base |
|---|---|---|
| Base | 2160p 60 Main 10 60-fps | -- |
| HDR | Dolby Vision | 10% to 25% of Base bitrate |
| 3D Audio + Interactive | Dolby Atmos® | 448-Kbps to 640-Kbps |
| HFR | 100/120-Fps | 5-Mbps |
| Total | -- | 25-Mbps |

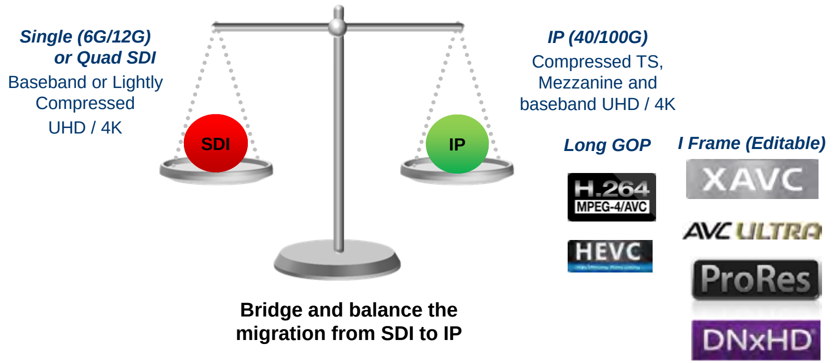
In regards to bandwidth, the broadcast industry has historically relied heavily on Synchronous Digital Interface (SDI) to transmit baseband or lightly compressed/editable content as the principle interface between equipment in production facilities. Yet the video industry is increasingly falling into line with enterprise networks by adopting IP as the primary backbone interconnect, and using standard router/switcher infrastructure along with generic 'big data' solutions. Yes, SDI will play a prominent role in early UHD production environments, but challenges will emerge from 40-G and 100-G Ethernet variants with the capacity to handle baseband production signals. To date, these interfaces have been slow to emerge and very expensive. It is still not inconceivable that the mild compression schemes for editing and long Group of Pictures (GOP) compression may breath life into SDI, especially in its 6-G and 12-G variants.

Even for 4K workflows, production and play-out storage remain challenged by the sheer volume that 4K production implies. For example, raw 4K/60-fps 10-bit depth compression requires 11-TB/hour of storage. ProRes is still massive when compared with 1080i (ProRes 4K/60-fps 10-bit depth compression 4444 requires 2-TB/hour compared with 1080i 150-GB/hour).

No surprise, then, that the concept of networked storage for production is not yet established, with most 4K workflows still bespoke, based around clustered local storage.

Interestingly, the Rio 2016 Olympics will not be produced in 4K, with virtual reality and 8K being the only formats selected beyond HD. From a commercial perspective, the decision not to distribute the Olympics in 4K is disappointing, although understandable given the technical hurdles facing widespread live UHD production.

**Exhibit 17 – Group of Pictures (GOP) Compression/Production Interfacing**



# UHD AUDIO

Next we examine innovations in the field of UHD-related audio, a component of great importance in defining the TV viewing experience.

## UHD TV Audio Concepts

- **Immersive Audio –** An audio system that enables high spatial resolution in sound source localization in azimuth, elevation and distance, and provides an increased sense of sound envelopment. These features are supported over the listening area. Such a system might not directly represent loudspeaker feeds but instead could represent the overall sound field.

- **Channel-Based Audio –** A set of audio signals that is intended to be rendered directly on loudspeakers in a specific 2D or 3D physical arrangement (e.g., 22.2, 7.1+4, 5.1, stereo and the like).

- **Object-Based Audio –** An audio signal with parametric metadata that in combination represent an audio source that is intended to be rendered at a designated spatial position, independent of the number and location of actually available loudspeakers. Audio objects may also be used for optional or adjustable audio elements for purposes such as dialog enhancement, alternate language, or other personalizable aspects. The object metadata may also control other parameters of the audio signal, such as volume, adjustment constraints and equalization.

- **Audio Rendering –** 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. 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 Relevance of UHD TV Audio

While UHD is widely known for the enhanced visual experience it provides, sound quality is also a defining component of the UHD viewing experience. With the upgrade to UHD TV, there is unique opportunity to improve the accompanying audio experience and to provide a UHD-equivalent sound experience that goes beyond HD-quality sound. UHD TV enables the delivery of enhanced audio quality and immersion, as well as new levels of personalization and interactivity.

To this end, UHD Phase 2 implementation requires audio capabilities beyond 5.1 surround sound such as object-based audio. Though DVB's initial specification was short on details, since that time multiple immersive audio formats (including Dolby AC-4 [standardized by ETSI and DVB], MPEG-H [standardized by MPEG] and DTS-X) have been developed to support both extended channel-based and object-based audio formats.

System manufacturers and others are working with industry organizations like ATSC, DVB, and ITU to establish standards for broadcast TV audio; standards that will be deployed along with UHD TV in the next few years. The ATSC, for example, is currently evaluating audio formats for its 3.0 standard and will have recommendations ready in late 2015.

A combination of contextual factors—including the growing array of display devices, shifting demographics, new video behaviors, and quantum access to a widening variety of video content—require that new video-related audio systems be immersive, personal, and widely accessible.

- New audio formats like Dolby Atmos deliver lifelike audio experiences to virtually any location, whether for public use (for example, in a theater) or personal use (at home or on the go). These new audio formats are being adapted to support a wide range of configurations, creating a new standard for TV audio quality.
- Tomorrow's video viewers will demand significantly greater control over their TV audio experience, including the ability to personalize sound to their tastes by controlling dialog, using alternate audio and commentary, mixing assistive audio services, and selecting various special effects.
- These systems must support both the normalization of content loudness and contouring of dynamic range based on the specific capabilities of a user's device and its unique sound environment.
- Finally, systems that enable multiple language switching, dialog enhancement, loudness management, and descriptive video services must meet regulatory requirements.

Catalyzing new opportunities are the dramatically improved efficiencies and greater capabilities offered by new audio formats like Dolby AC-4. As these formats are standardized and introduced by broadcasters and pay-TV operators, it will be necessary for the UHD TV infrastructure to support them and the innovations they offer.

### *Hypothetical Use Case: Multi-Camera UHD with Multiple Audio Feeds*

As the baseline size for UHD TVs moves to 55" and beyond, operators and content producers will have new opportunities for more creative delivery. For example, the presence of a larger screen can enable mosaics for sports content, as well as enhance interactivity. Case in point: viewing Formula-1 racing could be improved with simultaneous multi-car viewing, in-car viewing, or additional statistics. Users could not only select the video that they want to watch but also select which audio stream accompanies this programming.

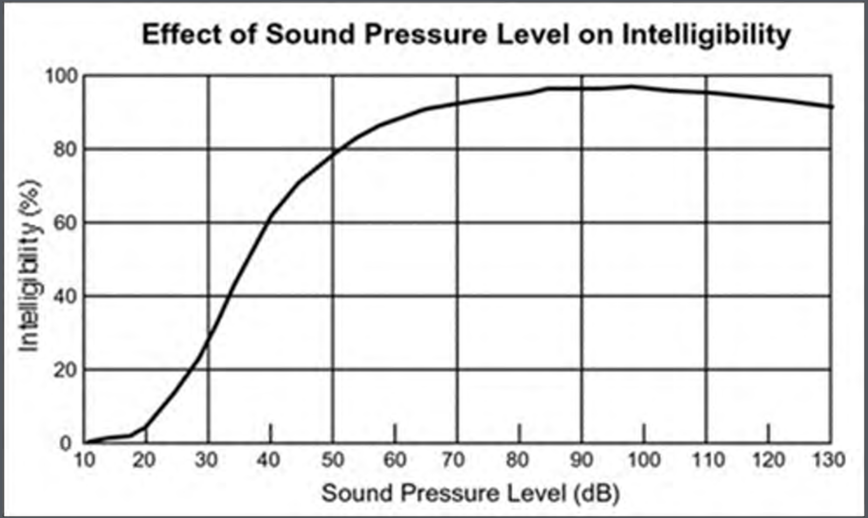
## Challenges Facing UHD Audio

A number of challenges must be addressed before the promises of an UHD TV audio experience can be actualized.

- **End-to-End Support** – In order to deliver superior TV audio, changes are required across the content creation and delivery ecosystem, including playback in the home. Broadcasters and pay-TV operators must work with standards organizations and equipment vendors to ensure that the audio created is actually delivered to the home in the way that the content creator intended.
- **Loudness and Dialogue Intelligence** – The roll out of UHD video has the potential to exacerbate problems currently experienced with HD video. For example, today's televisions are challenged to deliver high-quality audio over the types of speakers they support. This will only worsen as larger UHD televisions extend in-home viewing distances.
- **Content Creation and Availability** – As with UHD video, the lack of content that supports the new functionality provided by UHD TV audio could slow the adoption of this new functionality. Fortunately, this challenge is being addressed, with content creators and CE manufacturers adopting and supporting immersive audio solutions like Dolby Atmos. To date, over 250 movies have released in Dolby Atmos and companies like Amazon Instant Video and Netflix are now delivering these movies to the home.[2] With this growing pipeline of content and ecosystem support, this challenge will be addressed as UHDTV is deployed
- **Audio Bandwidth Requisites** – Due to their increased efficiencies, emerging audio formats provide new opportunities to deliver enhanced functionalities. Depending on the number and type of objects required, however, bandwidth requirements may be increased beyond today's capabilities.
- **Device Support** – Coordination with manufacturers of televisions, audio-video receivers, and speakers is critical in order to support rendering and playback of new audio formats associated with UHD TV Phase 2 and Phase 3.[3]

## Dialog and Audio Intelligibility

With the shift to UHD, the industry must confront a number of issues regarding loudness and dialog intelligibility. As defined by ISO, intelligibility is “a measure of the effectiveness of understanding speech” and is impacted heavily by the distance between the source and the listener, as well as the quality and directivity of the speakers delivering the sound. With today’s flat-panel displays (both HDTVs and UHDTVs) the ability to deliver high-quality sound directed at the viewer has become more difficult.




The migration to UHD televisions will only exacerbate this problem, as it drives the desire for larger screens designed to make the most of UHD’s higher resolutions at greater distances between the display and the viewer. As these distances increase, however, audio intelligibility declines. As speech travels from the source, the acoustical energy is spread over an increasingly large area and average speech levels fall at approximately 6 dB for each doubling of distance from the source. As illustrated, this reduction in sound volume can result in a significant loss in intelligibility, causing the user to reach for the remote to increase the volume.

This problem can be addressed by the inclusion of dialogue enhancement and object-based audio volume control. Dialogue enhancement improves the audibility and the intelligibility of dialogue and vocals relative to the rest of audio content for stereo music and video. It detects and extracts the dialogue into a separate speech channel, applies dynamic equalization, and intelligently mixes the speech channel back into the audio stream, which is particularly useful when the audio level is low—such as when watching TV late at night—or when the listening environment is particularly noisy. Combining dialogue enhancement with the ability to personalize the listening volume of only the dialogue offers a welcome solution to this growing problem.

Object based audio allows the operator to send the dialog as a separate audio object that the end user can control the volume level independent of the level other sounds in a program. This will allow the user to increase the SPL of the dialogue without an equivalent increase in overall program audio, thereby avoiding the loudness problem that would accompany just turning up the volume of the entire program.

# Infrastructure Requirements for Next-Generation Audio

As with video, the existing HDTV infrastructure will require updates in order to handle the extended requirements of UHD audio in general and for immersive audio in particular. For example:

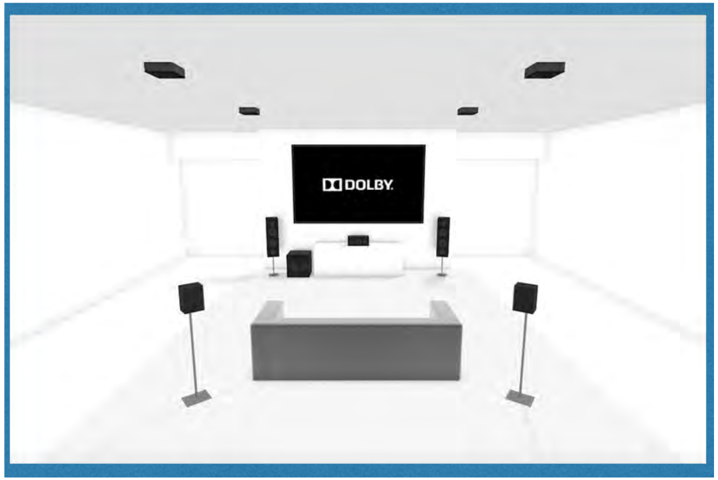
- Audio mixing facilities and sound design rooms may require upgrades to enable higher-quality audio. Creating immersive audio stipulates systems be outfitted with proper mixing and monitoring equipment.
- Uncompressed audio transport and bandwidth requirements must be defined for moving audio in a production environment.
- High-quality immersive audio bandwidth requirements and realistic delivery payloads must be defined. The efficiencies of new audio formats supported by UHD must be much greater than those used with HD.
- New interfaces may be needed throughout the audio infrastructure, including production and broadcast facilities, as well as in the home. This is necessary to handle immersive audio along with the higher bitrate video required for UHDTV.
- New in-home audio playback solutions may be required in order to enable immersive audio.

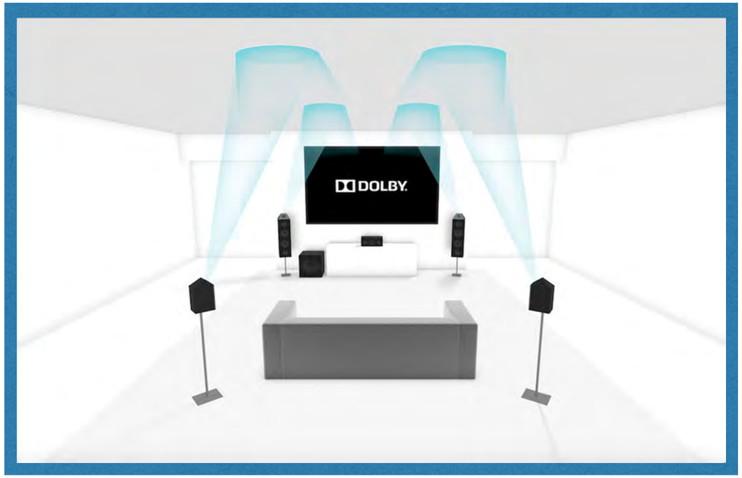
# Audio Playback and Sound Reproduction Considerations

Academy Award® winning writer-director George Lucas once said that sound is 50% of the movie-going experience. In a recent interview, *Trance* director Danny Boyle goes further: “The truth is…that 70-80% of a movie is sound. You don’t realize it because you can’t see it.”

In order to enjoy a video experience in line with the intentions of content creators, the sound system and room acoustics are every bit as important as the display. For example, a good home theater system can create a holographic space that puts the soundstage in front of the viewer. With immersive sound, such as that enabled by Dolby Atmos, the home theater system can create an entirely new experience, one in which the viewer is fully immersed and engaged.

A key part of delivering immersive audio in the home is the type of speakers used. There are a number of recommendations for speaker placement, with each audio format having its own recommendations. For example, the following illustrations show the recommended layout for a Dolby speaker solution. Either upward-firing or ceiling-mounted speakers can support this arrangement.




Not all consumers will deploy an immersive audio speaker arrangement. In fact, the widespread use of simpler systems like soundbars increasingly define the in-home AV experience. This is particularly true in China, where UHD TV uptake has progressed rapidly. In fact, one of the major TV retailers in China, Xiaomi, is bundling soundbars with many of its UHD TVs. Xiaomi understands the importance of high-quality audio to the TV viewing experience and incorporated the Dolby Stereo and DTS audio technology.[4] This will likely become a trend among TV manufacturers as the need for enhanced audio quality, and the demand to differentiate between increasingly commoditized hardware, becomes clearer over time.

Today's viewer engages video on a variety of devices and from a variety of sources. Consequently, sizeable amounts of content is being viewed both within and outside of the home; and on both the largest and smallest screens (smartphones). This is a corollary to viewers having more control over engagement — controlling the time, location, device, and content they wish to view (such is the very nature of quantum video). Only then does the video ecosystem enter into the equation, taking up the challenge of delivering to the end user the best video experience possible.

It is also true that cost matters, especially to when it comes to pay-per-gigabyte content delivery networks (CDNs).[5] The widespread use of adaptive bitrate streaming enables CDNs to manipulate the quality of video in order to deliver an uninterrupted stream. That said, for a large portion of viewers, greater convenience and quantum access trumps any absolute notion of quality.[6] This is especially true among Late Millennials between the ages of 18 and 24.

Case in point: a user accessing a video on their smartphone over a wide-area 3G/4G network has selected that mode for a specific set of reasons, most often associated with convenience and context. They understand perfectly well that the video quality displayed on a small screen from a (wireless) mobile broadband connection will not live up to the video quality displayed on their state-of-the-art living room television from a (wired) home broadband connection.

In short, UHD is not a one-size-fits-all solution, and there is no 'right' level of video quality (though creatives and consumers alike gravitate toward higher-quality video).

**Exhibit 16 – Video Resolutions, Bandwidth, and Screen Size**

| Video Resolution | Typical Bandwidth for Streaming | File Size for 60 Minutes of Video | Typical Screen Size and Use Case |
|---|---|---|---|
| 360p | 512 Kbps | 250 MB | Up to 10-inches; smartphones and tablets connecting via 3G/4G mobile networks |
| 480p | 800 Kbps | 400 MB | Up to 25-inches; smartphones, tablets, and PCs connecting via Wi-Fi |
| 720p | 2 Mbps | 1 GB | Up to 50-inches; high-quality PC and tablet video via Wi-Fi download (e.g., OTT streaming to smart TVs via ADSL networks) |
| 1080p | 5 Mbps | 2.4 GB | Screens 50-inches and larger at traditional TV viewing distances. High-quality streaming to HDTVs via wireline broadband networks |
| 2K (1440p) | 8 Mbps | 3.8 GB | Screens 50-inches and larger, possibly viewed at closer distances. Highest quality streaming possible on wireline broadband with sub-10 Mbps speeds. |
| 4K UHD (2160p) | 15 Mbps | 7.2 GB | Screens 65-inches or larger viewed at closer distances. Premium quality content captured in UHD and rendered in a home theater environment. |

Flexibility and adaptability rule the day. The table above provides a useful summary of today's most popular video resolutions and the types of devices on and settings in which they are most likely to be used.[7]

To this point we've focused on video and audio technologies that define the UHD ecosystem. Next we turn to the market context in which UHD technologies are evolving and being implemented. This section discusses the primary forces pushing UHD forward, as well as the principle obstacles standing in its way.

# UHD Drivers

## *TV Manufacturers*

Television manufacturers were among the first to step into the UHD arena. Declining sales, thinning margins, and the failure of 3D—not to mention the Great Recession of 2007-2009—created a very difficult environment for TV OEMs. Given their intrinsic desire to find the next ‘big thing,’ UHD/4K offered a proverbial panacea,[8] and OEMs were quick to introduce sets at a rapid clip.

As of March 2015, OEMs including Samsung, LG, Sony, Toshiba, Panasonic, Seiki, Sharp, TCL, Changhong, and Vizio were selling UHD TVs at major US CE retailers,[9] many of which include integrated smart TV capability, a feature critically important to the VOD use case. Unfortunately, the flood of UHD televisions created a cart-before-the-horse problem: there were plenty of UHD TVs on sale, but little in the way of UHD content to go with them (a market inhibitor discussed in the next section).

To address this issue, TV OEMs are focusing on dimensions of UHD other than resolution, such as HDR,[10] wider color range, and immersive audio, each of which take UHD to the next level. At CES 2015, vendors including Samsung, Sony, LG, and TCL featured UHD TVs with HDR, the benefits of which have been outlined extensively.

DOLBY VISION™

No doubt HDR is at the moment a hot technology space with at minimum five rival standards in play. The BBC, Dolby Philips, Sony and Technicolor have all proposed HDR schemes with SMPTE and the EBU, in conjunction with DVB, pursuing HDR and Wide Color Gamut standardization. Dolby has achieved significant market traction with Dolby Vision screens, prominently featured at CES 2015, while HDR is seen as a powerful tool for offline encoding for VOD applications. Hopefully this technique will build upon early 4K VOD adopters to expand the viewing experience of HDR encoding techniques for live UHD applications. As it stands, HDR techniques for offline applications are far more progressed for UHD VOD than UHD live. HDR for UHD live is far more challenging and a number of issues concerning bit depth and backwards compatibility will be crucial to make sure the needs of UHD VOD and live can be meant with a common HDR standard.

Among the leading technologies enabling HDR is Dolby Vision®, an end-to-end solution that starts with the creation of content and carries on through to distribution and playback. It already has secured support from TV manufacturers, OTT service providers, and infrastructure suppliers.[11] To date, Philips, Hisense, Toshiba, and TCL have committed to producing Dolby Vision-enabled TVs, with streaming services such as Netflix, Amazon, and Vudu hoping to distribute Dolby Vision movies and TV shows once they are available (which, given recent announcements by Warner Bros., will be sometime in 2015[12]).

### *Advances in Streaming Technologies*

Only a few years ago the idea of streaming UHD video over the Internet seemed impossible. Broadband users were primarily consuming short-form video in tiny windows on their PCs, a viewing experience that made original standard-definition DVDs look great. Much has changed since those early days, with two specific factors coalescing to make UHD video streaming technically feasible to transport and consume.

First, video streaming technologies improved dramatically, with the Motion Picture Experts Group (MPEG) and others developing HEVC (aka, H.265), a next-generation video codec that optimizes available bandwidth such that larger files can be transported more quickly and efficiently. HEVC offers real-world codec efficiency gains (i.e., bandwidth savings) of 25-30 percent compared to today's state-of-the-art codec, AVC.[13] Employing HEVC could mean the difference between needing a 15-Mbps and a 12-Mbps stream to deliver a UHD stream, thus opening up a large swath of broadband homes that would otherwise be on the bubble with respect to UHD content access.

Additionally, MPEG has standardized a new adaptive streaming format, MPEG-DASH, which dynamically adjusts video resolution to real-world device capabilities and bandwidth conditions.[14] As these innovations are added to televisions and ancillary devices, UHD (and near-UHD or 2K) streaming could reach many more viewers.[15]

Second, US consumer broadband speeds have improved dramatically over the last decade, with average wireline connection speeds now greater than 10-Mbps.[16] Moreover, the top-10 US states in regard to broadband speed all have peak connection speeds above 40-Mbps, well above that needed to deliver a UHD stream.[17]

Of course, not all US broadband users have access to such capacity. As noted in the FCC's eighth report on US broadband speeds, roughly 19 million Americans (more than 75% of whom live in rural areas) do not have access to *minimal* broadband (a 4-Mbps downstream service) and will not be streaming UHD content anytime soon.[18] Nevertheless, a majority of US broadband households in populated areas are now at or above access speeds necessary to support a single UHD stream.[19]

### *Content Creators/Owners*

Ultra-HD is important to content creators and owners for several reasons. First, creatives are by nature attracted to technologies that improve the quality of video experiences.[20] As a result, many (but not all) new movies are being shot in UHD, while movie theaters are also upgrading to show movies in UHD.[21]

Second, content owners have long understood that new formats can be a great way to get consumers to view (even buy) new versions of older movies and TV programs previously viewed in another format.[22] (*Star Wars*, for example, has been re-released so many times and with so many infinitesimal format-related changes that it has its own [extensive] Wikipedia entry cataloging these changes.[23]) Ultra-HD provides an opportunity to re-release classic movies in a new, higher-quality format, thus extending the value of a studio's content library.[24]

Finally, UHD streaming increases the value of on-demand content to a wider range of viewers, potentially expanding the market to include users who have heretofore avoided these services due to quality concerns.

### *OTT VOD*

Ultra-HD also presents OTT video providers with a number of prospects. A majority of UHD viewing will take place on televisions connected to wireline broadband, thus presenting to providers and consumers alike a very appealing use case. There are three reasons why OTT distributors like Netflix have been the first video service providers to embrace UHD VOD.

- First, UHD VOD is an extremely cost-efficient service (compelling combination of low distribution costs and high viewing value). While the benefits of UHD can in theory be extended to virtually every viewer, companies like Netflix only pay CDN costs for UHD content that is actually delivered. Modern adaptive streaming techniques mean that viewers capable of receiving a UHD stream will get it, and those who cannot will simply continue to view the same 720p or 1080p HD they already receive. Put another way, if only a few consumers watch an on-demand program in UHD, the additional cost to the provider for offering that program is minimal. There is a cost, of course, to encoding content in UHD, but for a small library of non-real-time content it is relatively minor. Moreover, UHD capture is already best practice for original content production, so extending the workflow to include a UHD encode profile is both logical and prudent for future-proofing a VOD library.
- Second, support for UHD video is likely to provide a ‘halo effect’ around video quality. For the first time ever, OTT operators will be capable of delivering a higher quality of video than legacy pay-TV providers. This will serve as a valuable tool in recalibrating consumer quality perceptions and reinforcing the value proposition of OTT services.
- Third, the largest SVOD OTT providers (Netflix and Amazon) already support UHD,[25] meaning Google and Microsoft cannot be far behind. With such forces embracing UHD, other OTT providers will quickly follow suit.


### *MVPD VOD*

Multi-service video providers (MVPDs) understand the very real threat posed by OTT services. Unlike Netflix and other online SVOD providers, however, MVPDs enjoy end-to-end control over their networks and services. They have (and will) look to exploit this advantage.

While deployment of linear UHD broadcasting faces significant economic and technology barriers, MVPDs can support UHD VOD for some of their subscribers at much lower costs than linear UHD. TDG expects the first high-end MVPD set-top boxes supporting UHD VOD to hit the market in 2015, which will undoubtedly serve as a positive driver for the entire UHD ecosystem.

## UHD Inhibitors

All new technologies require time and resources to diffuse. Ultra-HD is no different. Despite offering a marked improvement in video quality, the uptake of UHD faces significant challenges, the discussion of which is the purpose of this section.

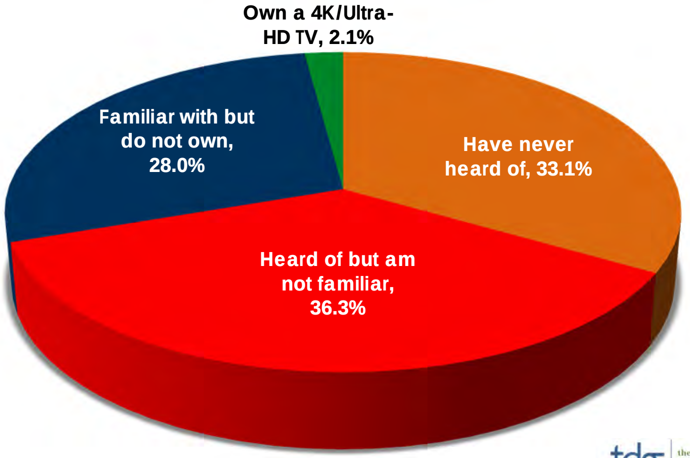
### *Lack of Consumer Awareness*

Ultra-HD/4K remains a 'bleeding edge' technology, poorly understood by mainstream consumers. As of Q1 2015, close to 70% of consumers were either unaware of or unfamiliar with UHD/4K televisions.[26]

Making matters worse and further confusing consumers, the market continues to use the terms '4K' and 'UHD' as if they are synonymous. Combine this with the lack of consensus among key players regarding UHD standards (that is, beyond the lowest common denominator of video resolution and aspect ratio) and short-term UHD diffusion appears problematic. It is imperative that the industry agrees upon a meaningful UHD profile that can be supported across the ecosystem--from content creation to consumption--and that can be clearly communicated to would-be buyers.

**Exhibit 17 – Familiarity with and Use of Ultra-HD/4K Televisions**

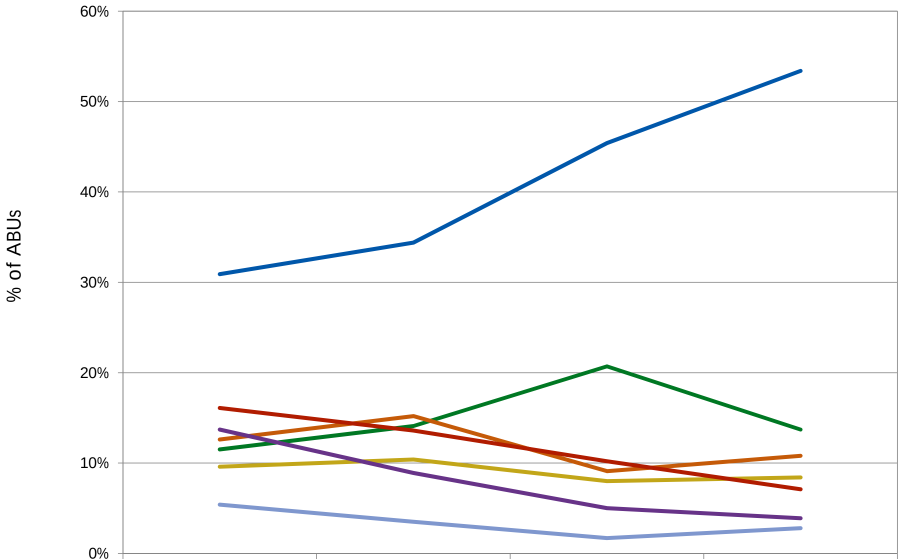
(among US adult broadband users, n=3,428)




Source: TDG Research, February 2015

**Exhibit 18 – Price Sensitivity in Purchasing New UHD/4K Television**

(among adult broadband users, n=3,428, prices randomly assigned, one price per respondent)




| | $999 | $1,499 | $1,999 | $2,499 |
|---|---|---|---|---|
| Definitely will not purchase | 30.9% | 34.4% | 45.4% | 53.4% |
| Moderately unlikely | 11.5% | 14.1% | 20.7% | 13.7% |
| Slightly unlikely | 9.6% | 10.4% | 8.0% | 8.4% |
| Neither likely nor unlikely | 12.6% | 15.2% | 9.1% | 10.8% |
| Slightly likely | 16.1% | 13.6% | 10.2% | 7.1% |
| Moderately likely | 13.7% | 8.9% | 5.0% | 3.9% |
| Definitely likely | 5.4% | 3.5% | 1.7% | 2.8% |

Source: TDG Research, February 2015

### *High Retail UHD TV Prices*

While eager to make UHD a mainstream phenomenon, TV OEMs position UHD/4K as a high-end capability for which paying high-end prices are justified. Unlike other consumer products such as cars or fashion merchandise, however, UHD televisions have questionable value as a luxury product because everyone consumes the same content (i.e., video programming).

Moreover, without a mass market for UHD TVs, there is no business model for content creators, and thus no UHD content for consumers to watch on their expensive new televisions. Yes, UHD set prices are falling, but 24 of the 52 current model-year UHD TVs available from Amazon still sell for $2,000 or more.[27] TDG research has consistently found that such pricing is excessive, with less than 2% of US adult broadband users actually set to purchase a UHD TV at a price of $1,999.[28]

Over the next 5-7 years, UHD televisions will work their way into mainstream homes, but only if prices are significantly lower than they are today. This is a critical requisite for the evolution of the entire UHD ecosystem, but it requires that TV OEMs (in their minds) prematurely lower the retail prices of a device they consider to be high-end. (This is reminiscent of what early Blu-ray OEMs faced when pushing the technology into the market. On one hand, they want the higher margins associated with 'cutting edge' technology. On the other hand, they want the higher volumes associated with mainstream positioning.)

### *High Costs of Upgrading Product Infrastructure to Handle UHD*

As noted earlier, 4K/UHD production is demanding on a variety of fronts including bandwidth, storage, and interfaces. 4K workflows will require upgrades to the infrastructure to handle the sheer volume that 4K production implies. For example, raw 4K/60 fps10-bit depth compression requires 11-TB/hour of storage and will likely require upgrades to the interfaces between all the elements in the workflow. So as far as providing UHD over broadcast, satellite, cable, or streamed over internet - the increased bandwidth required could necessitate big infrastructure costs, and with the cost incurred by broadcasters in the recent DTV transition, there will be clear hesitancy to upgrade their networks until the business model for UHD has been well proven.

### *The Lack of UHD Content*

In addition to hardware demand challenges, UHD's potential is further limited by the lack of a legitimate content support system, including content capture, creation, editing, storing, managing, encoding, and streaming. Even the resolution of video ads must be considered. For example, will consumers accept low-resolution ads in a UHD program, or will they demand ads be shot in UHD as well? The improvement of each support system components is contingent upon the existence an installed base of products based on industry-wide standards and technologies, and workflows that will not change overnight. In addition, there has to be a business case for filming content in UHD.

For example, it is widely known that movies shot in UHD still have visual effects added in 2K (or even 1080p) because current tools do not support UHD.[29] As well, re-mastering movies from film to UHD is a labor-intensive process, with experts reviewing and tweaking each frame of film.[30] (Sony's UHD re-mastering of *Lawrence of Arabia* took three years to complete.[31])

Furthermore, where UHD content does exist, traditional TV distribution paths are simply not available. For example, it will be several years before legacy pay-TV providers in the US are able to deliver UHD linear broadcasting. Deloitte recently estimated that the cost of creating a UHD broadcast channel is $10-$15 million, as much as seven times the $2 million it takes to create a new HD channel.[32] And while streaming UHD on-demand is less expensive than broadcasting live linear UHD, it is still more expensive to stream UHD on-demand than to stream HD on-demand. Despite HEVC's improved encoding efficiencies, delivering a UHD stream could cost a content provider three to six times as much as delivering today's (mainly 720p) streams.[33] Finally, and as discussed below, the current generation of physical media for video (i.e., DVDs and Blu-ray discs) do not support UHD.

### *Historically Long Television Replacement Cycles*

The television market in the US is overwhelmingly defined by a 6-8 year replacement cycle. With the exception of Early Adopters, this presents a fundamental behavioral impediment to rapid UHD television diffusion.

Despite aggressive efforts by the TV industry to mimic more rapid PC, tablet, and smartphone purchase cycles (that is, to induce *premature obsolescence*), the TV replacement cycle has remained relatively stable during the last decade. Moreover, consumers have learned that it is not necessary to upgrade their television in order to upgrade their TV experience, as illustrated by strong consumer adoption of low-cost Internet set-top boxes and sticks. As well, the availability of OTT UHD programming supported by such devices may actually lengthen the television replacement cycle.


### *Lack of UHD Support among Broadband TV Devices*

The vast majority of broadband streaming viewed on living-room televisions is currently delivered via ancillary Internet-enabled platforms that connect to a television using an HDMI interface. Over-the-top services like Netflix, HBO Go, Amazon Instant Video, and Hulu Plus are viewed on television primarily by means of game consoles (e.g., Xbox 360/One and PlayStation 3/4), Internet set-top boxes (e.g., Apple TV and Roku), Internet streaming sticks (e.g., Google Chromecast) and broadband-enabled Blu-ray players (from Samsung and other CE manufacturers).

By comparison viewing streaming video on directly-connected smart TVs remains relatively minor, accounting for less than 10% of total OTT TV viewing. This presents a significant challenge to UHD delivery because the net-to-TV platform, the television, and the HDMI interface between the two must *each* have UHD capability—if any of these elements is missing, there is no 'UHD experience.'

Historically, game consoles and physical discs have led the market in supporting new video formats. Unfortunately, the current generation of consoles (Xbox One and PlayStation 4) shipped in 2013 when UHD standards were in flux and are not UHD-capable. Equally frustrating, the industry has been far too slow to agree upon a single UHD Blu-ray standard.[35] As a result, today there are no UHD-capable ancillary TV devices in market, and it will be several years before component prices fall sufficiently to allow UHD capability in ancillary connected-TV devices at the price points required for rapid mainstream diffusion. Nevertheless, over the next decade, 4K-enabled streaming devices will eventually be deployed in the majority of US broadband households.[36]

The first comment to note is that smartphone and tablet support for 4k will primarily be driven by video capture rather than playback considerations. As discussed below, a UHD profile for mobile phones and tablets is possible, but will need to take into account the distinct audio and screen requirements of these devices. With respect to devices that enable 4k video viewing on TVs, iSTBs (i.e. Internet set-top boxes such as Apple TV, Roku and Amazon Fire TV) will lead the market with 4K-capable units present in over 60% of US broadband households by 2025. Of course, not all of these devices will be connected to TVs that support 4K resolution, leaving some of this capability unused. Nevertheless, no other device category offers more potential in terms of enabling the ecosystem. Bringing these devices into the discussion about UHD content profiles, as well the hardware interfaces necessary to deliver the resulting video from the iSTB into the display, will be critical going forward.

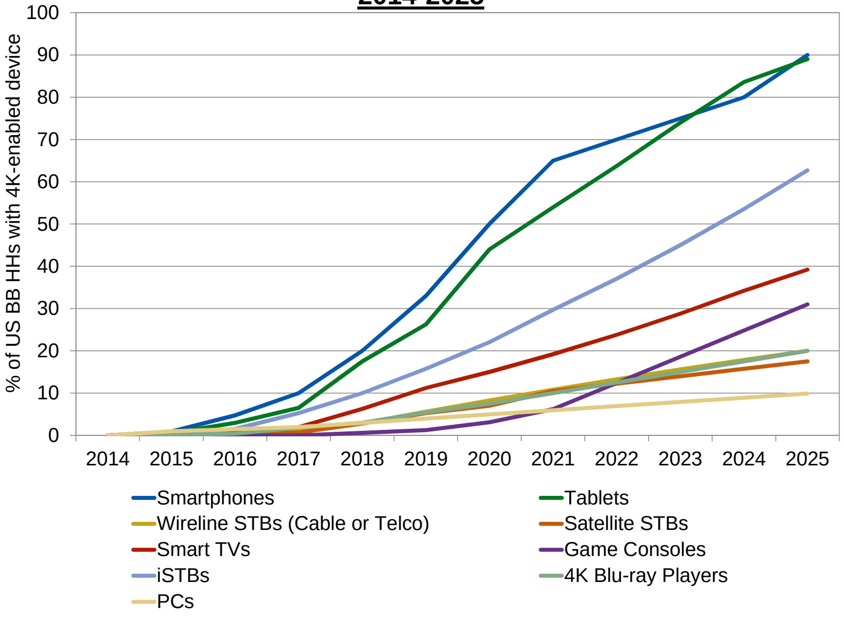
As to UHD televisions, sales will be modest for the next few years, as prices slowly fall and UHD TVs move from the high end into the broader mass market. In addition, consumers will be cautious until the industry achieves a broad consensus around UHD standards and profiles that ensure that content will be viewable at high quality on any UHD TV. After a relatively long incubation period, UHD television adoption will begin to accelerate in 2018 and beyond, reaching 11% penetration by 2019, 19% by 2021, and 40% by 2025. This constitutes solid growth for a new (and relatively expensive) consumer product competing in a saturated replacement market.

Additionally, UHD TV adoption will be spurred by upgrades of legacy pay-TV STBs. This will take time, but is expected to reach 20% for wireline and 18% for satellite STBs by the end of the forecast period. This results in nearly a one-to-one correspondence between UHD TVs and operator STBs capable of supporting them.

UHD Blu-ray players, for their part, will be an important niche product, expected to be present in 20% of broadband households a decade from now. This is substantially less than the 45% penetration of 1080p Blu-ray players today, but still a respectable market for a category (i.e., physical media) that will play a much more limited role in the video ecosystem going forward. Even more importantly, 4k Blu-Ray will play a useful role over the next few years in terms of helping set standards around UHD content and bridging the content gap for purchasers of UHD TVs.

Finally, PCs are declining in importance with respect to the online video ecosystem as a whole, but will also remain an important niche market and a potentially interesting segment for UHD enablement.

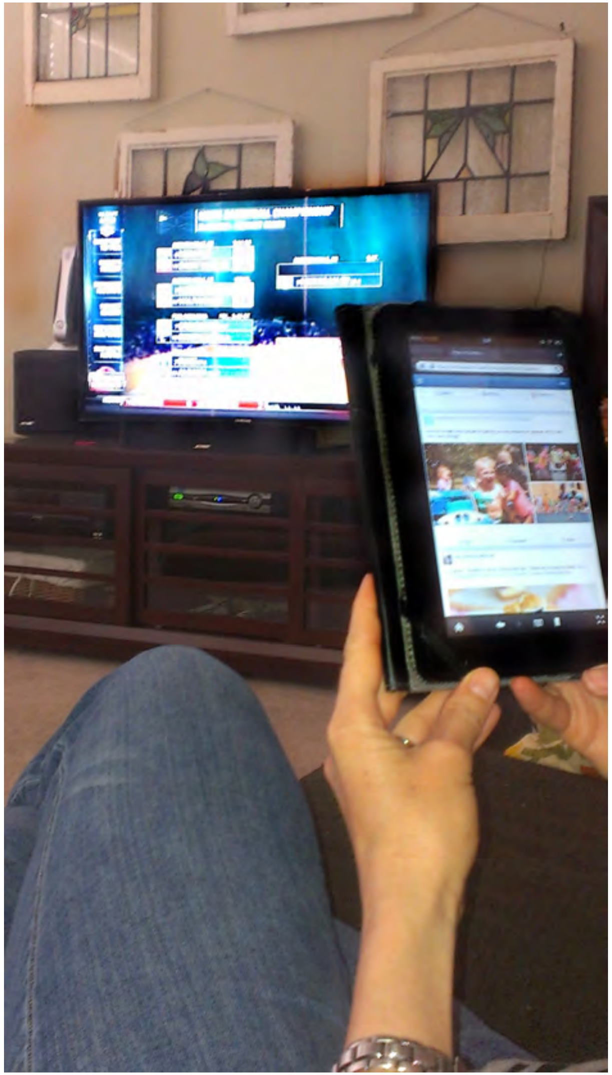
**Exhibit 19 – Penetration of 4K-Enabled Devices among US Households 2014-2025**



### *Mobile Video and UHD*

According to TDG research, video consumption is expanding from social viewing on living room televisions to individualized consumption on smaller screens. The fact that quantum video viewing is defined by multi-network, multi-screen displays means that the video ecosystem cannot be upgraded all at once, but will instead be defined by various sub-systems grappling with the diversity and complexity of client devices that simply did not exist during previous video upgrade cycles. For example, many of today's smaller screens already feature retina displays (meaning the eye cannot perceive the pixels displayed at normal viewing distances) at HD resolutions, meaning there is no clear benefit from upgrading to UHD. As well, smaller screens are simply too small to appreciate the greater resolution, while the file size and bandwidth requirements of UHD video are in most contexts too costly and demanding. This is where the other features of UHD, like HDR and enhanced audio come in to play. We believe that we will see some OTT service providers deliver a package of UHD that will be relevant both to UHD TVs but also mobile devices like tablets and PCs. With this in mind a number of device manufacturers have already started to deliver devices that will support these enhanced UHD features such as 3D audio. For example, Lenovo has announced the Lenovo® A7000—the world's first smartphone to incorporate Dolby® sound and Amazon had previously announced the Kindle Fire 8.9 HDX with support for Dolby Atmos sound.

Thus content providers must be equipped to deliver UHD video to owners of UHD TVs, while simultaneously delivering the same content in lower resolutions to owners of non-TV devices including smaller screens such as PCs, tablets, and smartphones (where UHD will be the exception, not the rule).



# CHALLENGES OF DEPLOYING UHD

Among the key challenges to the future of UHD is articulating the business case for different industry stakeholders. Given that UHD content will be delivered by a variety of service providers—each with very different capabilities, business models, legacy platforms, and content types—the nature of challenges faced will vary, as well. We turn next to the issues faced by key video service providers.

Broad deployment of UHD content remains challenging. Simply adding UHD video profiles is not a strategy. Instead, video providers must articulate and journey through a planned evolution. This section discusses how different types of providers can best go about incorporating UHD into their business roadmaps.

## OTT Providers and Vendors

As previously noted, OTT providers are the first to embrace UHD content, leveraging pervasive broadband and the growing diffusion of UHD televisions. These virtual operators are able to reduce the costs of content delivery (while delivering QoS) by using adaptive streaming technology. These video providers are today leading the UHD charge with original and licensed UHD studio content, and are subsequently setting the tone for the entire market.

At the same time UHD video presents real challenges for OTT services. First, much of the video consumed from these services is and will be viewed on smaller screens (i.e., personal computers, tablets, and smart phones, in that order), which benefit least from a shift from 1080p to UHD resolution. Second, most video viewed on smart TVs is viewed via third-party streaming devices, not native smart TV implementations. To address these challenges:

- Start capturing original video in 4K resolution. 4K cameras are now in market from leading vendors like Sony, Panasonic, and BlackMagic, and it is better to have the extra resolution and not need it than need it and not have it (as long as ROI permits).
- Focus on native smart TV apps as the first place to support UHD. Working with partners who can support secure MPEG-DASH streaming to these devices will help aid the transition. These apps may migrate to third-party streaming boxes as the consumer hardware ecosystem around UHD matures.
- Create UHD-ready content by using encoding tools from leading providers like Harmonic® that provide support today for the profiles consumers will want tomorrow.

# Legacy TV Providers & Vendors

Ultra-HD poses a quandary to legacy pay-TV providers. Their subscribers will purchase UHD TVs with the expectation that their TV provider will have UHD content to view, only to find the content unavailable. Operators run a very real risk here, as consumers frustrated with the lack of UHD will no doubt blame pay-TV providers (not the OEMs are retailers that sold them the set). And as incumbent operators take the heat, OTT providers are busy pushing the UHD envelope. If this trend is left unchecked, it could pushing consumers away from pay-TV services and toward OTT services.

There are no easy answers to these challenges, but following these commonsense steps will set pay-TV providers on the right path.

- Add UHD support for VOD first. This has many benefits: fast time-to-market, dramatically lower costs, and significant marketing benefit vis-à-vis higher RPU households who are looking for UHD content to watch.
- Authenticate TV Everywhere (TVE) apps on iSTBs and smart TVs. Blocking these devices is just handing viewers over to the competition and giving them a chance to build beachheads in the UHD ecosystem. TVE apps must be market-competitive to OTT services, including support for UHD streaming profiles.
- Add UHD playback capabilities (including support for unicast streaming) to new operator STBs as soon as possible.
- Align UHD roadmaps and capabilities with leading partners and profiles to ensure that your service capabilities align with the consumer's expectations.

Different delivery networks pose significantly different challenges and opportunities for pay-TV providers. We provide specific thoughts for each of the major pay-TV network categories.

## *Direct-to-Home*

Direct-to-Home operators enjoy The most latitude regarding UHD content delivery. To date, DTH providers have decided to either send VOD files in carousel mode (push VOD), or create their own UHD channels based from VOD files (linear playout) or broadcast live linear events. Such distribution is primarily done via satellite, though some operators are considering IP-based delivery. The logic is straightforward: for a small amount of viewers, unicast delivery with a good QoS is the best choice. If content is scarce, VOD delivery is preferable to broadcast (assuming the content in question is not live). Direct-to-home operators have always been among the first to introduce new video formats (e.g., HD or 3D), and it is not unreasonable to expect them to be the first to jump on the UHD format, this time with an IP delivery option that did not exist before.

## *Cable*

Cable operators currently deliver broadcast channels over QAM, but with advances in DOCSIS technology (3.0 moving to 3.1) there is now enough capacity to deliver UHD over IP. If the number of sessions is relatively few, unicast streaming should be sufficient and more complete multicast schemes can be postponed until the UHD market reaches critical mass. Cable operators are now offering VOD over DOCSIS, though they have historically lagged DTH providers in this regard. That said, DOCSIS 3.X allows cable operators to react more quickly, thus minimizing lag time, all the more if they can put more pressure on the telecommunications providers who, for the most part, are limited to slower DSL connections.

## Broadcasters

Broadcasters face difficult choices with respect to UHD. Upgrading the legacy OTA broadcast infrastructure poses significant challenges.

First, broadcasters must convince regulators to grant them more frequency, which is necessary to deliver UHD over-the-air. Spectrum is scarce and costly, particularly for bands that can also service mobile data networks. It is not clear that broadcasters can (or should) compete with large nationwide mobile operators in an open bidding war for spectrum.

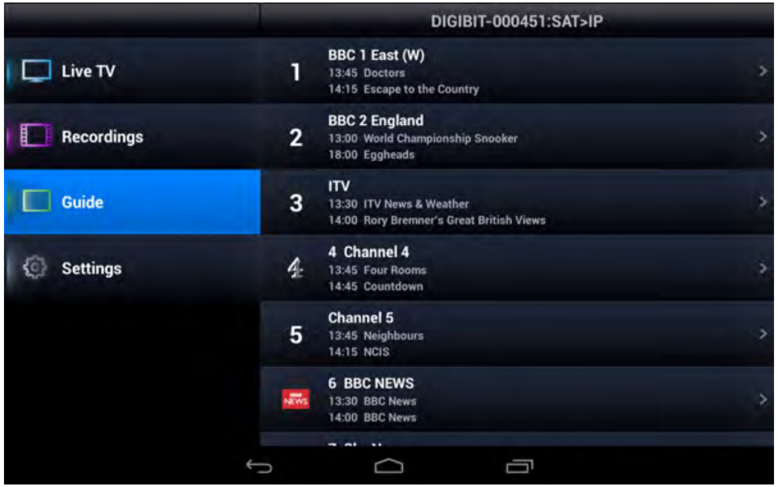
Second, as a significant amount of broadcast content is still distributed live, UHD broadcast would require a major investment in new production capabilities. In a world of flat (or even declining) ratings for traditional broadcasters, it is likely to be extremely difficult to justify the business case for such an investment. Last, but certainly not least, televisions must be able to receive and decode the signal, which means interested consumers must purchase both a UHD TV and a new UHD OTA antenna. This does not currently represent a significant addressable market.

Third (and potentially most interesting), broadcasters must launch UHD content within their own direct-to-consumer OTT services. Going direct means the broadcaster must 'own' the viewer, with all the opportunities and challenges a direct relationship entails. For example, broadcasters running their own OTT services bear all the costs of building and supporting apps for the widest array of platforms, as well as the CDN costs of delivering content. In the case of UHD, these incremental costs may be small initially (due to the small number of simultaneous UHD viewers on a given app), but could scale rapidly if a show becomes a hit. Such costs are already evident, as illustrated by the massive CDN outlays associated with the BBC's iPlayer HD service. Both CDN cost and capacity will for the foreseeable future limit the practical ability to provide live UHD streams of popular content.

The more attractive short-term path is for broadcasters to act as content providers, producing and licensing UHD content to both pay-TV and OTT providers. As previously discussed, these providers will for the foreseeable future be focused on VOD-based UHD content, meaning broadcasters can select individual shows for production and licensing in UHD format without the concern of creating linear-based UHD channels. While this is clearly the path of least resistance, it does pose risks to a broadcaster's brand and may conflict with the its general streaming strategy, which may be shifting from a wholesale model (i.e., license to aggregators) to a retail model (i.e., direct-to-consumer apps).

## IPTV Operators and Vendors

Given the fact that most telco operators are confined to DSL-based video delivery, network speeds remain a significant challenge. The majority of DSL connections support downstream network speeds of 25-Mbps or less, which is only minimally adequate for UHD delivery. Unicast delivery of UHD VOD can work, however, especially for content that is not live. Content could also be downloaded and stored on the local hard-drive of an operator STB. Wider-scale deployment of UHD, however, may require significant investment in FTTX. Operators with fiber-based networks are in a much stronger position and should move aggressively to capitalize on their advantage by offering HD VOD services. In either case, telcos will have to deal with customers trying to view third-party UHD content (i.e., Netflix) over their broadband connection.




DOLBY harmonic

## Content Creators/Owners

Ultra-HD poses a dilemma for content owners. Their traditional distributors and dominant revenue sources (i.e., pay-TV operators) are not yet offering UHD content. On the other hand, OTT providers (e.g., Amazon and Netflix) are beginning to support it. Content owners cannot passively wait for an industry-wide rollout of UHD. Instead, they must play an active role in building the UHD ecosystem, taking concrete steps as follows:

- Support content production in UHD wherever possible in order to future-proof one’s solutions, as well create strategic alternatives. This requires a real investment in UHD-friendly capture and editing tools, but is the only way to future-proof today’s content investment for tomorrow’s UHD content deals.
- Upgrade existing encoding and streaming infrastructure to support UHD technologies.
- Build apps for connected TV platforms like iSTBs and smart TVs, not just smartphones and tablets. Without content on the devices that will be able stream UHD content, existing providers are ceding the entire UHD market to content produced by OTT providers.
- Look for opportunities to participate in early UHD VOD trials and service deployments, which will provide valuable experience and validate the end-to-end workflow. Partner with leading vendors and begin experimenting with UHD now. Select 1-2 popular shows that have strong followings on connected TVs and offer a UHD profile.

## UHD Business Models

The table to the right summarizes how different verticals conceive of the UHD business model. Remember, we are in the early days of UHD and the factors impacting the various UHD business models are evolving in real time. For example:

- UHD standards have yet to be defined, with several iterations competing for supremacy (ITU-R, HDR, DVB, etc.).
- The costs of producing live UHD programming are very high but will decline as new solutions emerge to streamline live production.
- UHD compression technology is in its infancy, with efficiencies expected to improve in the next years.
- Semiconductor and display technologies used in HDR are continually improving.
- Today's ill-populated UHD content library will improve over time but incrementally, as more UHD content is created using standardized formats.

**Exhibit 20 – UHD Business Models: Requirements & Challenges**

| | Content | Delivery | Device | Business Model |
|---|---|---|---|---|
| OTT | Produced by the operator or licensed from 3rd-parties | No upfront investment, use existing CDNs on a per-gigabyte basis | UHD TV sets and ancillary net-to-TV platforms | Balance CDN and content licensing fees vs. additional revenue and improved brand image |
| DTH | License from third parties | Upgrade DTH infrastructure or rent ISP capacity, CDNs are an option with reduced quality of service | Operator STBs or UHD TV sets | Balance DTH capacity/ISP rental/CDN, content licensing, and STB costs vs. additional revenue and improved brand image |
| Cable | License from third parties | Updated DOCSIS 3.X infrastructure | Operator STBs or UHD TVs | Balance DOCSIS investments, STB and content licensing costs vs. additional revenue, selling better data plans, and improved brand image |
| Telco | License from third parties | Update DOCSIS 3.X infrastructure | Operator STBs or UHD TVs | Balance fiber investments, costs of delivery mechanisms, content licensing, and STBs vs. additional revenue, upsell to FTTX, and improved brand image |
| Broadcast | Produced by network | Upgrade DTT network (new frequency, new modulation, new codecs, etc.), OTT as an option | UHD TVs for DTT and OTT, operator STBs | Balance DTT network and production costs vs. additional revenue from operators, selling premium OTT services, and improved brand image |
| Content | Produced by studios and networks | OTT as an option | UHD set for OTT, operator STBs | Balance rights acquisition and production costs vs. revenue from operators and OTT delivery |

Based on the assessments presented in this section, OTT VOD currently offers the most compelling business case, primarily due to the lack of costs associated with building out network infrastructure. On the other hand, QoS is not guaranteed, as an adaptive streaming mechanism is required for uninterrupted video delivery. Additionally, when content is streamed live and attracts a large audience (such as with sporting events), the economics of UHD OTT become prohibitive.

Conversely, the economics of delivering UHD via traditional broadcast become challenging when the number of customers using the service is low—thus the current dominance of unicast streaming for delivery of popular live events. A key benefit of unicast streaming is that QoS can be guaranteed on DOCSIS and fiber networks. Of course, content producers will be a determining aspect for all UHD business models, meaning that if the costs of UHD content production are too high, consumers may shy away from buying a UHD television and accessing UHD content, which means gridlock. For this reason, the costs of UHD content must decline over time (and they will).

As well, we anticipate diverse UHD business models will emerge as innovations manifest and UHD starts to take off. And while UHD may currently be at the chicken-and-egg stage and profitability may seem difficult, once UHD televisions begin to diffuse the rest of the value chain will follow. Very soon *not* having access to UHD content will be an anathema to consumers (aka, the service users that pay the bills).

# FINAL THOUGHTS

The path to UHD may be challenging but there is no doubt that its diffusion is inevitable—the tide cannot be turned back. Companies in the video value chain will prosper or decline based on how they come to terms with UHD.

As discussed, aside from a four-fold increase in resolution, UHD enables:

- Higher frame rates (thus smoother motion);
- Higher dynamic range (thus brighter brights and striking contrast);
- Greater color depth (thus a much wider color gamut vis-à-vis the current HD standard); and
- Dramatically improved audio (thus enhanced depth and space of video-related sound with unprecedented levels of personalization)

As with any new technology, the path to mainstream UHD uptake is defined by both opportunities and challenges. Mastering market drivers, addressing market inhibitors, and planning for the ebbs and flows of path to UHD requires collaboration and cooperation across the ecosystem. Most importantly, industry stakeholders will need strong partners who are committed to the UHD ecosystem and capable of forging the business and technology consensus needed to move forward.

The technology is maturing. The standards are coming together. And the consumer trajectory is set. Now it's time to determine how your company can make the most of the shift to UHD.

# ENDNOTES

[1]Though each of these companies refers to their solutions as 'UHD 4K,' they are UHD, not 4K. This is just one instance of how the two terms are used improperly, most often for marketing purposes.

[2]Brett Crockett "Dolby Atmos Goes Mobile in the Amazon Fire HDX 8.9 Tablet," http://blog.dolby.com/2014/09/dolby-atmos-goes-mobile/ (accessed March 17, 2015).

[3]John Eargle & Chris Foreman, "An Examination of Bandwidth, Dynamic Range, and Normal Operating Levels," http://www.prosoundweb.com/article/print/an_examination_of_bandwidth_dynamic_range_and_normal_operating_levels (accessed on March 20, 2015).

[4]"Mi TV", http://www.mi.com/en/mitv/ (accessed March 19, 2015).

[5]Dan Rayburn, "The Dirty Little Secret About 4K Streaming: Content Owners Can't Afford the Bandwidth Costs," http://blog.streamingmedia.com/2014/01/dirty-little-secret-4K-streaming-content-owners-cant-afford-bandwidth-costs.html (accessed July 18, 2014).

[6]TDG, unpublished research.

[7]This chart is synthesized from multiple public sources including Apple, Google, and Xvid, as well as discussions with encoding professionals at Divx, Inc.

[8]Se Young Lee, "LG Posts Weakest Quarterly Profit in Two Years after New-Year Lull," http://uk.reuters.com/article/2014/04/23/uk-lg-display-results-q-idUKBREA3M0A020140423. (accessed March 24, 2015).

[9]TDG survey of Amazon, Best Buy, Walmart, and Fry's websites.

[10]Janko Roettgers, "UHD is TV's Next Big Thing. So Why is the Industry Divided?" https://gigaom.com/2015/01/13/uhd-is-tvs-next-big-thing-so-why-is-the-industry-divided (access on March 24, 2014).

[11]Andrew Clough, "CES 2015: 4K, HDR, Quantum Dot and Dolby Vision Explained," http://www.whathifi.com/news/ces-2015-4k-hdr-quantum-dot-and-dolby-vision-explained#AEkz8UxfIsx1eahC.99 (accessed on March 24, 2015).

[12]Dolby Press Release, "Warner Bros. Home Entertainment and Dolby Announce Collaboration to Bring Hollywood Blockbuster Content in Dolby Vision to Home Distribution Partners," http://investor.dolby.com/releasedetail.cfm?releaseid=889514 (accessed on March 24, 2015).

[13]"Coding Efficiency," http://en.wikipedia.org/wiki/High_Efficiency_Video_Coding#Coding_efficiency (accessed March 18, 2015).

[14]"Overview of MPEG-DASH Standard," http://dashif.org/mpeg-dash/ (accessed July 18, 2014).

[15]Ibid.

[16]*State of the Internet Report* (Akamai, 2014) http://www.akamai.com/stateoftheinternet/ (accessed March 25, 2014).

[17]Ibid.

[18]*Eighth Broadband Progress Report* (FCC, 2012), http://www.fcc.gov/reports/eighth-broadband-progress-report (accessed March 24, 2014).

[19] Ibid.

[20]Tom Eames, "James Cameron: Avatar Sequel to be Shot in 4K, Partially High Frame Rate," http://www.digitalspy.com/movies/news/a552071/james-cameron-avatar-sequels-to-be-shot-4K-partially-high-frame-rate.html (accessed March 25, 2015).

[21]Ryan Nakashima, "*After Earth* among First Movies to be Shot, Shown in 4K," http://www.ctvnews.ca (accessed on March 25, 2015).

[22]Shane Greenstein, "Format Wars All Over Again," Northwestern University Faculty Blog,, http://www.kellogg.northwestern.edu/faculty/greenstein/images/htm/columns/formatwars.pdf (accessed April 1, 2015).

[23]"Lists of Changes in *Star Wars* Re-releases," http://en.wikipedia.org/wiki/List_of_changes_in_Star_Wars_re-releases (accessed March 24, 2015).

[24]Todd Spangler, "Sony Gears Up for 4K Ultra HD Internet Movie Service," http://variety.com/2013/digital /news/sony-gears-up-for-4K-ultra-hd-internet-movie-service-1200489195/ (accessed March 24, 2015).

[25]Ibid.

[26]Michael Greeson, *Benchmarking the Connected Consumer* (TDG, 2014). Note: given the fact that UHD non-4K sets are still being marketed as UHD televisions, survey questions include both 'UHD' and '4K' to test awareness and use of UHD TVs.

[27]Ibid.

[28]TDG press release, "Lack of Awareness and Price Sensitivities Plague Short-term 4K TV Demand," http://tdgresearch.com/tdg-lack-of-awareness-and-price-sensitivities-plague-short-term-4K-demand/ (accessed March 24, 2015).

[29]Alice Truong, "4K is Already Playing at a Theater Near You, but You Probably Didn't Even Notice," http://www.digitaltrends.com/photography/4K-is-already-playing-at-a-theater-near-you-but-you-probably-didnt-even-notice/ (accessed March 24, 2015).

[30]James Rivington, "Six Marvels of the 4K Revolution at Sony Pictures Studios," http://www.techradar.com/us/news/television/tv/six-marvels-of-the-4K-revolution-at-sony-pictures-studios-in-la-1146838 (accessed March 24, 2015).

[31]Ibid.

[32]"4K Kicks Off," http://www2.deloitte.com/global/en/pages/technology-media-and-telecommunications/articles/tmt-media-predictions-2013-4k-kicks-off-deloiite-tmt-predictions.html (accessed March 24, 2015).

[33]Dan Rayburn, "The Video CDN Business is Flawed, YouTube Subsidizes Video Delivery Bandwidth on the Net," http://blog.streamingmedia.com/2013/03/the-cdn-business-is-flawed-youtube-subsidizes-video-delivery-bandwidth-on-the-net.html (accessed March 24, 2015).

[34]"Shorter Television Replacement Cycles Mean Good News For Corning," http://www.corning.com/news_center/features/TV_replacement_cycle.aspx (accessed March 24, 2015).

[35]Steve Ray, "4K Streaming is Leaving Blu-ray in the Dirt," http://www.techradar.com/us/news/ television/hdtv/4k-streaming-is-leaving-blu-ray-in-the-dirt-1247111 (accessed March 24, 2015)..

[36]Joel Espelien, *Forecasting the 4K Video Ecosystem*, 2015-2025 (TDG, 2014) http://tdgresearch.com/report/forecasting-the-4k-video-ecosystem-2014-2015/ (accessed on March 24, 2015).

[37]Joel Espelien, *TV Gets Personal: Trends in Mobile Video Viewing, 2015-2025* (TDG, 2015) http://tdgresearch.com/report/tv-gets-personal-trends-in-mobile-video-viewing/ (access March 24, 2015).

[38]"The World's First Smartphone to Feature Dolby Atmos," http://www.dolby.com/us/en/categories/smartphone.html (access March 24, 2015).

DOLBY harmonic

# GLOSSARY

**Audio Rendering** – 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. 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.

**Channel-based Audio** – A set of audio signals that is intended to be rendered directly on loudspeakers in a specific 2D or 3D physical arrangement (e.g., 22.2, 7.1+4, 5.1, stereo and the like).

**CIE 193** – Links physical pure colors in the visible electromagnetic spectrum with the perceived colors in human vision. Most commonly expressed as a color space, either RGB or XYZ.

**Colorimetry** – A term associated with the science and technology used to describe human perception of color.

**Color Gamut** – The entire range of colors which can be accurately represented in a given circumstance, such as within a given color space or by a certain output device, such as a TV monitor. The larger or wider the gamut ,the more rich saturated colors are available.

**Color Grading** – The process of altering and enhancing the color of a motion picture, video image, or still image to match what the producer, director and colorist feel is appropriate for the story. Modern color correction, whether for theatrical film, video distribution, or print is generally done digitally in a color suite.

**Color Space** – A specific organization of colors. In combination with physical device profiling, it allows for reproducible representations of color, in both analog and digital representations. A color model (e.g., sRGB or Rec. 709) is an abstract mathematical model describing the way colors can be represented. Adding a specific mapping function between a color model and a reference color space establishes within the reference color space a definite "footprint", known as a gamut, and for a given color model this defines a color space. When defining a color space, the usual reference standard is the CIELAB or CIEXYZ color spaces, which were specifically designed to encompass all colors the average human can see.

**Color Volume** – The accessible gamut for a device depends on the brightness; a full gamut must therefore be represented in 3D space. The 3D color space defines the color gamut for differing luminance levels.

**Dynamic Range** – The ratio between the brightest and darkest parts of a picture. Specifically the term relates to a ratio of luminosity and is a vital element to map human visual perception to electronic media.

**Group of Pictures (GOP)** – Group of Pictures refers to a sequence after video compression has taken place. The GOP describes the resulting sequence and what type of frame was created (Intra or Inter).

**HDCP** – High-bandwidth Digital Content Protection is a common copy protection mechanism developed by Intel to protect connection of consumer digital media, commonly deployed between a set –top box, pvr or game console and a screen.

**HDR** – High-dynamic-range imaging (HDRI or HDR) is a set of techniques used in imaging to reproduce a greater range of luminosity than standard digital imaging. The aim is to present the human eye with a similar range of luminance as that which, through the visual system, is more lifelike. HDR enables content creation and distribution of images with higher luminance dynamic range and wider color gamut. For example, while typical TVs today have a peak brightness of approximately 100 nits, the peak brightness of an HDR television is around 1,000 nits.

**Immersive Audio** – An audio system that enables high spatial resolution in sound source localization in azimuth, elevation and distance, and provides an increased sense of sound envelopment. These features are supported over the listening area. Such a system might not directly represent loudspeaker feeds but instead could represent the overall sound field.

**Interlace Format** – A method to reduce the bandwidth of a signal, yet retaining the ability to track motion in a scene, by splitting a picture into two fields. One field consists of even numbered lines and the other field consists of odd lines. The fields are scanned and displayed sequentially. Adopting such a strategy achieves a crude form of bandwidth reduction of analog signals whereby the temporal frame rate is sustained by updating one odd field followed by an even field.

**Nit** – A measure of light intensity, equal to 1 candela per square meter. Inside an office building, the ambient brightness is a few hundred nits. A sunny sky (not looking at the sun) is about 10,000 nits.

**Object-based Audio** – An audio signal with parametric metadata that in combination represent an audio source that is intended to be rendered at a designated spatial position, independent of the number and location of actually available loudspeakers. Audio objects may also be used for optional or adjustable audio elements for purposes such as dialog enhancement, alternate language, or other personalizable aspects. The object metadata may also control other parameters of the audio signal, such as volume, adjustment constraints and equalization.

**Progressive Format** – An image format where the vertical scan starts from the first line, top of screen, and completes every line sequentially until the end line, bottom of screen.

**Progressive Resolution (ProRes)** – A production compression CODEC from Apple that handles resolutions up to and including 5K.

**Rec. 709** – Formally known as ITU-R BT.709, Rec. 709 defines technical parameters relating to scanning (Interlace and Progressive), aspect ratio and chrominance sampling; defines the HD 1080 x 1920 format.

**Rec. 2020** – Formally known as ITU-R BT.2020, 3840 x 2160 (4K) or 7680 x 4320 (8K), Rec. 2020 is a progressive scan format with an aspect ratio of 16:9 and square pixels; defines the two beyond-HD resolutions (4K and 8K).

**WCG** – Acronym *for Wide Color Gamut*, which describes any video format that can represent a wider range of colors than non-augmented HD.

## About Dolby®

Dolby Laboratories (NYSE: DLB) creates audio, video, and voice technologies that transform entertainment and communications in mobile devices, at the cinema, at home, and at work. For nearly 50 years, sight and sound experiences have become more vibrant, clear, and powerful in Dolby®.

For more information, visit www.dolby.com

## About Harmonic®

Harmonic is the worldwide leader in video delivery infrastructure for emerging television and video services. Harmonic enables customers to produce, deliver and monetize amazing video experiences, with unequalled business agility and operational efficiency, by providing market-leading innovation, high-quality service, and compelling total-cost-of-ownership.

For more information, visit www.harmonicinc.com

Join the UHD conversation with Harmonic

Harmonic Blog

Ultra-HD Encoding & Delivery

## About The Diffusion Group™

TDG provides actionable intelligence on the quantum shifts impacting consumer technology and media behaviors. Our market research and advisory services help technology vendors, media companies, and service providers understand how consumers access, navigate, share, and consume broadband media—whenever and wherever they may be.

For more information, visit www.tdgresearch.com