Canon

WHITE PAPER

CINEMA EOS

HIGH DYNAMIC RANGE (HDR) WHAT IT IS AND WHAT IT IS NOT

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CINEMA EOS

High Dynamic Range (HDR)

What it is and What it is Not

1.0 Imaging Parameters that Contribute to High Picture Quality

Over many decades the television and video technical community have wrestled with continually improving specific imaging parameters that collectively combine to elevate the overall quality of video pictures. This work evolved progressively over the extended era of analog video, followed by digital "standard definition" video (SDTV), all the way to todays' digital "high definition video (HDTV). Figure 1 summarizes contemporary consensus on the key imaging attributes contributing to high-performance HD digital motion imaging and that remain the focus of a global quest for improvements.

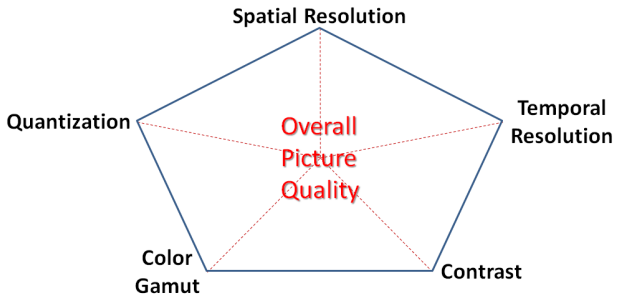

Figure 1 *The five key imaging parameters critical to high overall motion picture performance*

2.0 Priorities in Technical Developments on Imaging Parameters

From the mid 1970's to the present day there has been an almost universal fixation on elevating the imaging parameter of resolution. Digital sampling for video production formats went from 720 x 480 (SDTV) to 1920 x 1080 (HDTV) to 3840 x 2160 (UHD) – and from 2048 x 1080 to 4096 x 2160 for digital cinema. And, 7680 x 4320 (8K UHD) is already under development. In the move from SDTV to HDTV the important imaging parameters of color gamut and contrast remained much the same as SDTV (some minor advances).

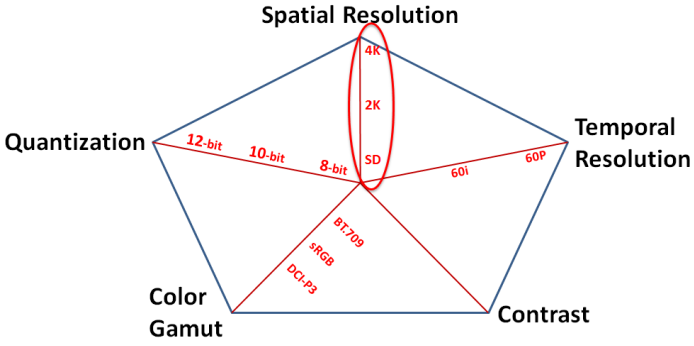

Figure 2 *The rapid expansion in video production specifications from about 1970 through 2010*

The Study Groups of ITU's Telecommunication Standardization Sector (ITU-T) assemble experts from around the world to develop international standards known as ITU-T Recommendations which act as defining elements in the global infrastructure of information and communication technologies **[1].** Around 2006 the ITU set about a major effort in developing recommended standards for the emerging era of 4K UHD and 8K UHD. Their initial focus remained heavily oriented to the associated major increase in system resolution.

Meanwhile, significant technological advances in image sensors and associated digital video processing paralleled quite astounding advances in display technologies (both on the consumer and the professional front). The rapidly increasing adoption of high resolution digital motion imaging for theatrical motion picture production spurred increase attention to enhancing color reproduction and extending picture contrast. It was within this stirring environment that interest in High Dynamic Range (HDR) and Wide Color Gamut (WCG) began to rise. The industry would soon learn about the important linkage between the two – and as a consequence begin to speak of "Color Volume".

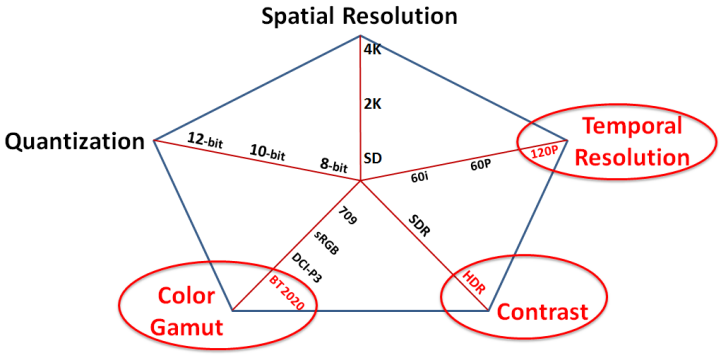

Figure 3 *Over the past five years a worldwide preoccupation with other image performance parameters has emerged – most especially in the areas of Color Gamut, Contrast, and Frame Rate*

Somewhat separately, higher picture capture rates have also surfaced as an area of increasing interest because 4K and 8K fast motion imagery on large screens can reveal temporal limitations not so evident with HDTV. Today, all parameters for enhancing overall image quality have been recognized in the new Recommendation published July 2016 by the ITU **[2].** However, at this moment HDR is center stage.

3.0 The Underlying Premise of HDR

Considerations of HDR starts with understanding that our human visual system (HVS) has wonderful capability in terms of our ability to view real world scenes under an enormous range of scene illumination – from blinding sunlight to dim starlight. Our HVS cannot instantly do this if we are suddenly moved from one extreme of illumination to the other. The HVS must adapt over time.

To understand the discussion on HDR it is important to first become familiar with a small associated vocabulary. There are terms that define important specifications associated with HDR. First, it is important to distinguish between the light levels that are *illuminating* a given scene and the light that is *reflected* from objects within that scene – which ultimately impinges upon our human visual system.

3.1 Illuminance

Scene illumination could be natural light from the sun, the moon, starlight – or artificial lighting such as night street lights, studio lights etc. This lighting is simply termed **ILLUMINANCE** – and is measured in units called **Lux**. Figure 4 illustrates typical illumination levels encountered in our real world environments (the scale is logarithmic because of the enormity of the range).

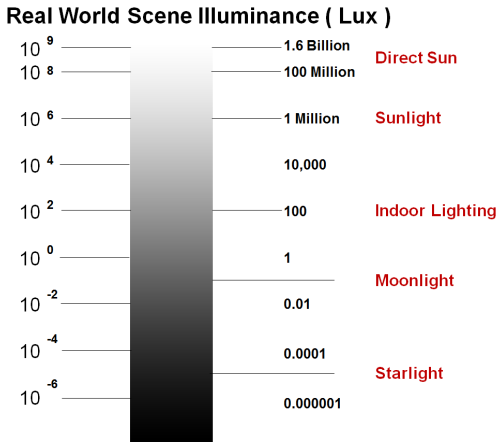

Figure 4 *Illustrating typical real world illumination levels measured in Lux*

3.2 Luminance

The scene illumination strikes all objects and the light reflected from each is what allows the human visual system to see those objects. That reflected light is called the scene **LUMINANCE** and is measured in units called **NITS.** More scientifically, one Nit is equal to one candela per square meter (1 cd / m²)

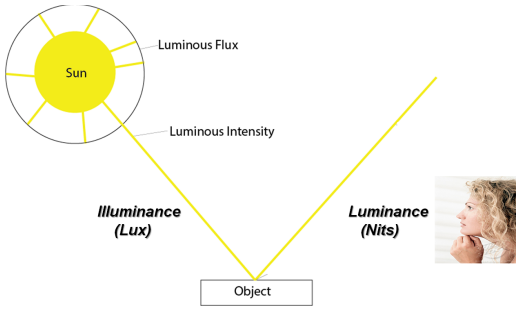

Figure 5 *Scenes are illuminated and our HVS see the reflected Luminance from all objects in the scene*

Our human visual system is capable of simultaneously clearly perceiving details in shadowed portions of a scene and details in the much higher brightness areas of that scene. We are also capable of readily perceiving very high levels of scene brightness. Consumer television displays cannot come close to those levels of peak brightness – nor to the simultaneous portrayal of details in both highlight and low light portions of a given scene. The quest for HDR displays seeks image portrayal closer to what we see in the real world. It is first and foremost driven by *the desire to achieve a far more realistic portrayal of detail in highlight and shadowed scene areas – that is, a higher dynamic range*. Secondarily it seeks the ability to also portray much higher peak brightness levels.

4.0 A High Dynamic Range Benchmark – the Human Visual System (HVS)

Within a given illumination situation there is a "steady state" for our HVS – when it settles into a quiescent state of adaptation – where we are capable of seeing a dynamic range in the vicinity of 6000:1 under normal daylight illumination **[3]** (Note: that number is still the topic of numerous contemporary studies and there are currently a variety of different conclusions – so consider it as a ballpark number).

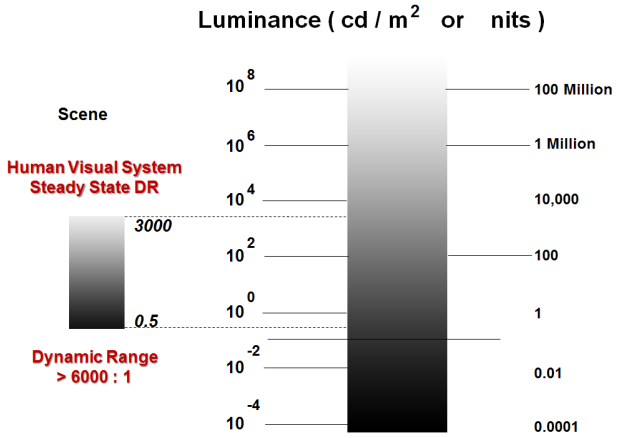

Figure 6 *Illustrating the approximate steady state dynamic range of the Human Visual System*

When we move from a bright sunlit scene to a more muted illumination (some indoor environment) our HVS goes through an adaptation process following which we essentially regain the steady state capability. This shift in perceived luminance is illustrated in Figure 7.

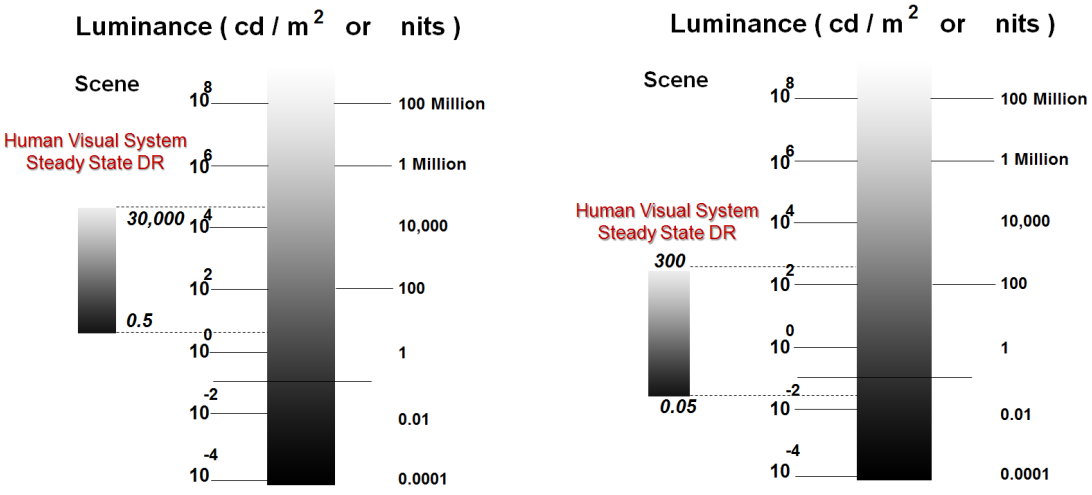

Figure 7 *Showing the adaptation process of the HVS when moving between two different levels of scene illumination*

5.0 Dynamic Range of Earlier Television Displays

For many decades television displays have had significant limitations in what they are able to portray in terms of peak brightness, black levels, and overall dynamic range. The longstanding CRT displays had a modest peak brightness capability in the vicinity of 100-200 nits. Under ideal conditions their black levels could be quite low and as a consequence they might deliver a dynamic range as high as 1000:1. When the CRT finally gave way to the new larger flat screen LCD and plasma displays there was not a significant alteration in the peak brightness capabilities. There was, however, deterioration in the black levels of those early LCD displays and overall dynamic range was reduced compared to the CRT.

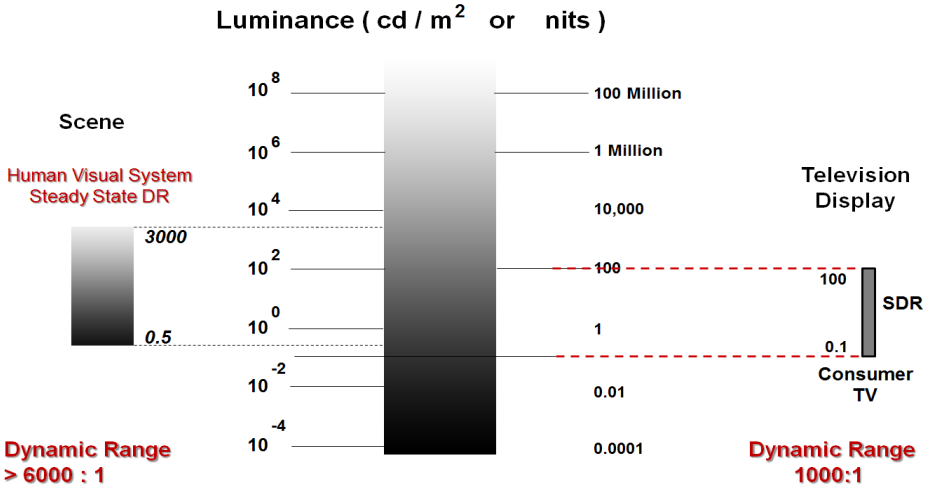

Figure 8 *Comparing the dynamic range of a typical consumer television display to the steady state dynamic range of the HVS*

Because of all of this we have been long accustomed to the separation between our real world viewing experiences and the very different experience of home television viewing. It can be said that the television image is a radical remapping of what the camera lens originally saw. We have become accustomed to the enormous disparity of this remapping and accepting of the limitations inherent to the television viewing experience. Up to now, we did not know any better.

6.0 The Dolby Lab Proposal – Birth of Industry Consideration of HDR

But display technologies began to advance with increasing rapidity – a result of radically diverse new display technologies and an increasing number of global manufacturers. It was within this new environment that Dolby took the bold step of messaging the professional and consumer world that a new era was imminent in television viewing. The essence of the Dolby alert was that technology was now moving fast to where we could anticipate a convergence between the normal real world human viewing experience and the television viewing experience. We could anticipate future television images delivering both far higher peak brightness levels and steady state dynamic ranges approaching our steady state 6000:1. Ultimately, their foresight would become embodied in their own Dolby Vision **[4].**

Back in 2012, at the height of the ITU developments on a standard for "*Parameter Values for UHDTV Systems for Production and International Programme Exchange*" Dolby Labs of the United States formally submitted a paper that argued that the new UHD standard should anticipate the ever accelerating advances in image display technologies and accordingly incorporate an appropriate display electro-optical transfer function (EOTF). A summary key sentence from the Dolby paper read:

"The new UHDTV signal should be able to represent, via the EOTF, a brightness range from 0.001 nits to something on the order of 10,000 nits, with non-linear code values such that contouring/stepping is never visible with the specified bit depths (10-12 bits)."

This submission was immediately met with broad skepticism. Few could conceive of television displays ever making the technological leap from 100 nit peak brightness levels to levels measured in the thousands of nits. Paradoxically, new developments in disparate display technologies were already showing substantial increases in both peak brightness and better control over black levels. This vision of fast-paced advances in television display capabilities soon triggered a vigorous global debate within the ITU that gave birth to the current very contemporary discussions on High Dynamic Range (HDR).

6.1 HDR – What it is NOT

HDR is not simply a dramatic elevation in television screen brightness

6.2 HDR – What it IS

The essence of HDR image portrayal is increased brightness accompanied by that significant expansion of dynamic range – where both the brightness of the highlights and all their associated details are elevated to better emulate the real world while at the same time the display can also portray details in deep dark portions of a scene. This offers the viewer a portrayal having far higher scene contrast than the legacy television viewing experience.

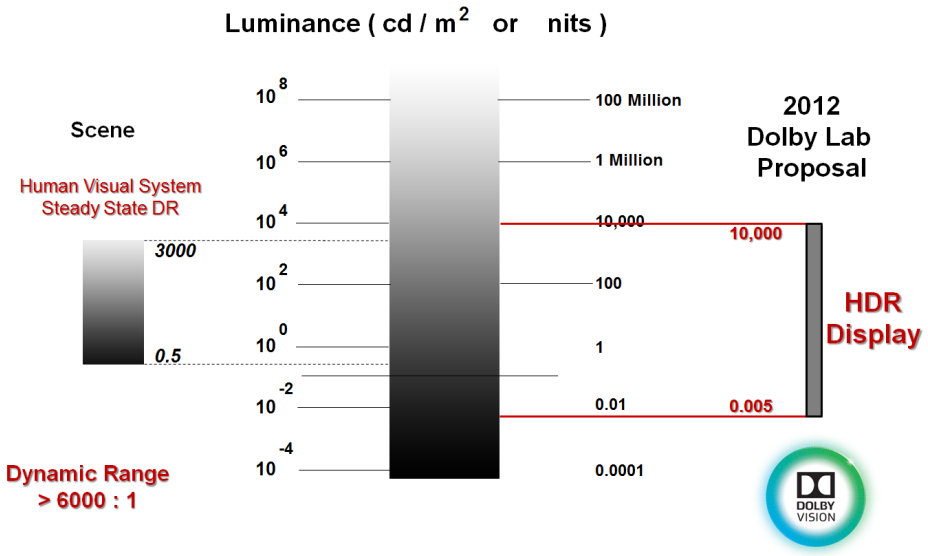

Figure 9 *The proposal of Dolby Labs spurred the global consideration of standardization that anticipated continuing evolution of very wide dynamic range displays*

7.0 The Visual Promise of HDR

The promise of HDR from the viewpoint of television home viewing is summarized in Figure 10. This is a simplistic representation of a contemporary HDR television display (there are others already emerging which have even more extended HDR ranges).

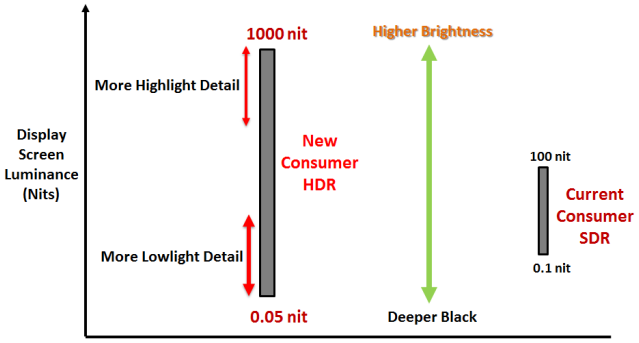

Figure 10 *Comparing the image contrast enhancement offered by a typical contemporary HDR display to that of the traditional SDR display*

High Dynamic Range is all about higher peak brightness and, most important, a substantial expansion in portrayed scene contrast. This combination can significantly enhance outdoor scenes making them more true to life. Highlights such as the sun through tree foliage are brighter and far more natural. Reproduction of the subtle contrast variations in clouds while still clearly distinguishing them from the blue sky background becomes possible. More accurate reproduction of speculars within a high contrast scene adds a higher sense of reality.

At the same time, the HDR display offers equally significant enhancements to low light scenes such as dimly lit interiors and external night scenes. Movie directors and producers of major television episodics traditionally love to exploit dark moody scenes to convey heightened drama. A new ability to portray subtle contrast and color variations in dark clothing and their textures in very low light scenes is supported by HDR. And again, reproduction of speculars is greatly enhanced (colors of Christmas tree lights within lower lit environment). Contemporary color grading in postproduction offer extraordinary capabilities in successfully extracting and reproducing extremely low signal levels that may be immersed in camera noise. As long as the camera is reproducing those low levels they can be capitalized upon by creative program producers. This is a topic that will be discussed in detail in a future new white paper on the C300 Mark II.

8.0 HDR and Color Volume

Color volume is a relatively new term within the current industry discussion on enhanced color reproduction. The subjective appearance of colors on a display is the collective of its hue, its saturation, and its brightness (or lightness, as it is more generally termed). Those who study colorimetry have long known that the colorfulness of a given color can be increased when its luminance is increased. This is known as the "Hunt Effect" **[5].** This three-dimensionality of color suggests a volume – and indeed, the term "color volume" is increasingly referred to in contemporary discussions of HDR portrayal.

An important addition to the image enhancement offered by HDR is this elevation of colorfulness by virtue of the entailed higher luminance levels. New displays are exhibiting progressively wider color gamuts allowing them to portray a wider range of real world colors while HDR enhances the portrayal of these colors. The combination of HDR and WCG is offering image enhancements that had not been anticipated by many – and we can anticipate a steady evolution in color volume portrayals **[6].**

HDR STANDARDIZATION

9.0 The Urgent Need for Industry Standardization of HDR

While the new capabilities of HDR displays is the central driver behind HDR there are attendant significant workflow issues related to producing HDR program material. There are even larger infrastructural considerations when HDR program material must be passed through a television broadcast system **[7].** These relate to the associated management of that same program material for the extensive legacy television systems and home displays – now referred to as Standard Dynamic Range (SDR) systems. Hence the current industry focus on HDR standardization

10.0 New ITU Standard for High Dynamic Range Television

On July 5th, 2016 the ITU announced a new standard for ***"High Dynamic Range Television"*** that represents a major advance in television broadcasting. The standard is **ITU-R BT.2100**. It is intended to build further upon the superior color fidelity of ITU's Ultra-High Definition Television (UHDTV) Recommendation BT.2020. This new standard was developed in collaboration with worldwide experts from the television industry, broadcasting organizations, and regulatory institutions – within its Study Group 6.

Figure 11 *Showing the published international standard for UHD on the left and the new international standard for HDR Television on the right*

The ITU-R BT.2020 standard on the left is exclusively dedicated to 4K UHD and 8K UHD. A great deal of the worldwide examination of HDR and WCG was initially focused on linking these critical image enhancements to the two UHD production formats.

11.0 2K / HDTV and HDR / WCG

The new ITU-R BT.2100 standard squarely includes the 1920 x 1080 HDTV production format with the two 4K UHD and 8K UHD production formats in terms of implementing both HDR and WCG.

This is extremely important because HDR and WCG were initially almost exclusively linked with 4K UHD and there were some in the global industry who felt they should have no part in the HD production formats. Including HDR / WCG in the standardized 2K / HD production formats has been a position strongly supported by Canon from the beginning – in recognition that 1080P will continue for many years while UHD slowly grows. The new ITU has come down squarely in support of 2K / HD.

12.0 The Industry Mobilizes in Support of HDR

In light of the speed with which developments were unfolding in digital motion imaging technologies the industry has responded with unusual rapidity. In 2015 two separate industry organizations were assembled to grapple with both the unfolding television displays offering 4K UHD resolution and various levels of HDR and WCG, as well as the complex infrastructural issues that especially surround HDR. The two organizations are briefly described below. While they are separate they are not in conflict but rather they are cooperating with each other.

12.1 UHD Alliance

In January 2015 the UHD Alliance was created **[8].** It comprises more than 35 member companies – a global coalition of leading film studios, consumer electronics manufacturers, content distributors, and technology companies aligned to foster the creation of an ecosystem that fully realizes and promotes the next generation premium in-home entertainment platform. The Alliance believes that key characteristics of a robust next generation experience should offer 4K resolution as well as a mix of other features that include high dynamic range, wide color gamut, high frame rate and immersive audio, among other features.

The Alliance developed three specifications that cover consumer devices, distribution and content. The chart below summarizes the particular specification that covers television displays – if they are to qualify for the **Ultra HD Premium** logo. What is of particular note is the dual specifications they agreed to for the HDR portion of this specification. This is in recognition of the different display technologies that presently underlie UHD televisions – specifically LCD and OLED.

Television Displays

Image Resolution:	3840x2160
Color Bit Depth:	10-bit signal
Color Palette	(Wide Color Gamut)
Signal Input:	BT.2020 color representation
Display Reproduction:	More than 90% of P3 colors
High Dynamic Range:	SMPTE ST2084 EOTF

Contrast Performance:

A combination of peak brightness and black level *either*:

> 1000 nits peak brightness
< 0.05 nits black level — **LCD Displays**

or

> 540 nits peak brightness
< 0.0005 nits black level — **OLED Displays**

12.2 Ultra HD Forum

Separately formed in 2015, the Ultra HD Forum **[9]** is a global organization responsible for promoting market adoption of Ultra HD by defining industry best practices for the phased introduction of the wide set of technologies facilitating the next-generation television experience. Many of the members are also members of the UHD Alliance

The organization facilitates interoperability testing and collaborates with industry standards bodies to align standard development activities. A list of participating member companies and additional information about the organization is available at http://ultrahdforum.org. During NAB 2016 the Forum released the first phase of industry Guidelines on end-to-end workflows for creating and delivering live and pre-recorded UHD content. The intention of this release was to let the Forum's growing membership of 46 organizations target product deployments in 2016. Both technical and commercial challenges are addressed such as production, distribution and consumer decoding of UHD programing with both SDR and HDR content.

13.0 Summary

This paper is confined to introducing the basic concepts underlying the present industry preoccupation with High Dynamic Range. HDR is considered by many to be the most important new enhancement to the television viewing experience – primarily because it is so visible and is essentially independent of consumer viewing distance. That enhancement applies to 2K / HD as much as it does to 4K / UHD images. In future white papers we will look more closely at how HDR impacts Canon products.

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