Projection Image Quality Series

White Paper #3: High Dynamic Range
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Welcome

From data visualization to simulation, planetariums, museums, trade shows and theme park attractions, projection users are demanding higher image quality. But what is image quality? Does it result from one feature – or some combination? How is the onrush of 4K changing the field? What about High Dynamic Range, called by many professionals\textsuperscript{1,ii,iii,iv,v} the most important advance in image quality? And how can today’s installation designers make informed choices?

To answer these questions, Sony has created a series of three white papers. If you’ve been following this series, you’ve seen the importance of 4K in delivering more information, more realism and more immersion – giving installers the ability to optimize these attributes for each application. You’ve seen how the SXRD® microdisplay delivers native 4K resolution and superb native contrast. Now we reach the capstone of our story: High Dynamic Range (HDR).

Picture quality is advancing on all fronts, transforming the viewing experience.

In this paper, we’ll see how HDR ties it all together, delivering a fundamental transformation in electronic image reproduction. We’ll see that achieving HDR means deeper blacks as well as brighter highlights. Getting the most out of HDR also entails superior grayscale rendition and wider color gamut.

This paper will define HDR in the context of human visual perception. We’ll walk through the powerful advantages of HDR. And we’ll see how 4K resolution and the performance of the SXRD microdisplay come together with HDR to establish a new benchmark in projection image quality.
Dynamic Range defined

If 4K is about more pixels, then HDR is about better pixels. In audio, “dynamic range” defines a system’s breadth of reproduction from the softest possible sounds (limited by the noise floor) to the loudest (limited by the distortion ceiling). In video, it’s the breadth of reproduction from the darkest possible black to the brightest possible highlight.

In electronic imaging, Standard Dynamic Range (SDR) struggles to capture detail in the brightest highlights and deepest shadows.

Compared to conventional, Standard Dynamic Range (SDR), HDR delivers images with unprecedented immersion and impact. You’ll see it in flight simulations, when pilots approach the runway going towards the sunset. You’ll see it in combat simulations, when warfighters peer into the fog, looking for the approaching enemy. The advantages of HDR are evident in dome presentations, with color and contrast beyond what could be achieved just a few short years ago. And in theme park rides, great HDR content will make the experience that much more compelling.

SDR falls short of human vision.

The human visual system is incredibly versatile. We can perceive light values from $10^{-6}$ candelas per square meter (cd/m$^2$) for starlight all the way to $10^{8}$ cd/m$^2$ for direct sun.$^\text{vi}$ That’s a ratio of 100,000,000,000,000:1. This is essentially our “dynamic contrast ratio.” However, “simultaneous contrast ratio” is another matter.
To accommodate the range from starlight to sunlight, our eyes need to adjust. At any given instant, the human visual system can “only” accommodate a luminance range of $10^6$. Think of this as a “simultaneous contrast ratio” of 100,000:1.

To accommodate such a broad range of light levels, your eyes need to adjust, a process that takes some time. Part of that adjustment is a change in iris opening. Like the human eye, television and cinema cameras also have adjustable irises that operators use to accommodate the difference from daytime to nighttime light levels.

Within a single scene, the human visual system’s dynamic range is far more limited, on the order of 100,000:1. Even this narrower range is beyond the reach of conventional television technology. Early television cameras couldn’t capture 100,000:1. CRT televisions couldn’t display 100,000:1. Analog TV broadcasting, 8-bit digital recording and 8-bit HDTV broadcasting struggle to preserve all the nuances of a 100,000:1 image. For all these reasons, conventional, SDR reproduction has been stuck with a dynamic range closer to 1,000:1.
SDR television systems can’t match the dynamic range of the human visual system.

The HDR opportunity

Since the 1950s, a suite of technical advances has made the limitations of SDR increasingly obsolete. For the first time, it is now practical to create an end-to-end television system that comes close to reproducing the human visual system’s 100,000:1 capabilities. This is High Dynamic Range.

The current generation of digital motion picture and TV broadcast cameras can capture HDR. Today’s professional digital recorders feature 10 bits or more of precision, capable of recording HDR. The very latest professional monitors, such as Sony’s TRIMASTER® models, enable directors and cinematographers to evaluate HDR images on-set during the shoot and also during critical postproduction processes such as color grading. New display technologies can deliver HDR to movie theaters, projection domes, simulators and televisions. For the first time, we can convey this entire 100,000:1 range all the way from the camera set through to the viewer.

HDR preserves the 100,000:1 range of human vision.

HDR benefits

HDR can improve every type of content, not just movies and TV shows, but also simulations, data visualization, fine art displays and dome presentations.

Greater impact

Compared to HDR, SDR is a pale imitation of life. We’ve seen that SDR falls far short of the contrast you experience in real life, while HDR can achieve that contrast. Images become more vibrant, more compelling and more involving. The advantage is most obvious in scenes.
with dynamic extremes: fireworks, pyrotechnics, sunsets or city skylines lit up against a deep black night sky. You see blacker blacks, higher peak brightness and better tonal gradations in between.

Nighttime cityscapes are a classic demonstration of HDR. A proper presentation of this effect would require HDR authoring and HDR viewing, conditions that do not apply here. The best we can provide are simulated images that only approximate the true comparison.

More information

With SDR, detail is in constant danger of being lost in the darkest and brightest areas of a scene. Content creators call these losses “crushed blacks” and “clipped highlights.” SDR forces cinematographers to monitor and limit scene dynamic range. HDR transcends this limitation, revealing detail across the full range of scene illumination.
This pair of simulated images illustrates how SDR clips highlight details and crushes black details that HDR retains.

In these simulated images, the SDR presentation can't accommodate the dynamic range from bright sunlight to stadium shadow. HDR can.
Greater sharpness

Distinct from resolution, “sharpness” describes the subjective impression that an image creates. The concept of TV system sharpness was rigorously defined in 1948 by Otto Schade.\textsuperscript{vii} He recognized that achieving sharpness requires both resolution and contrast. Working together with the 4K resolution of Sony projectors, HDR supports a significant boost in the contrast of content. So sharpness is visibly better. Picture details will “pop” as never before. Images will be crisper and more lifelike.

In these simulated images, the resolution is identical. Only the difference in contrast accounts for the higher perceived sharpness.

Sony built the GTZ Series projectors to deliver all these benefits. If you supply proper HDR source material and operate the projector in a proper environment, the image is staggering.
Picture quality enhancements associated with HDR

Accompanying HDR are two major image enhancements. Improved grayscale rendition and Wide Color Gamut present tremendous opportunities to content creators and Image Generators. HDR also works in concert with 4K Ultra HD resolution. So you’re not just getting a wider range of tones, you’re also getting more pixels on which to apply them. HDR and 4K work synergistically to deliver more organic images – a picture more like life itself.

Improved grayscale rendition

In theory, we could imagine an HDR video system with one-bit encoding. A digital 1 could represent white, while a digital 0 could represent black. In practice, we need our video pictures to represent grayscale values between peak white and black. And that requires more bits. Conventional HD recording systems, HDTV broadcasting and conventional Blu-ray Disc all represent images with 8-bit digital samples.

While careful observers will sometimes see issues, under most circumstances these 8-bit samples are sufficient to represent SDR images. But when you try to squeeze HDR images into an 8-bit pipeline and then stretch HDR back out on the screen, problems tend to appear. Tonal gradations that should appear smooth and continuous can become visibly stair-stepped. The problem, called “banding” or “posterization,” is bad enough on still images. On moving pictures, it can be extremely distracting. So along with High Dynamic Range, 4K Ultra HD can also deliver higher bit depth, such as 12-bit image capture and distribution. Because major HDR distribution channels are opting for 10-bit, our discussion will focus on that.

In these simulated images, crude grayscale rendition (left) causes horizontal banding in the sky. This artifact is absent in the image on the right.

In digital pulse code modulation, each additional bit of accuracy doubles the number of available quantization levels or “codelevels” available in the three channels (whether R/G/B or Y/Cb/Cr). While 8-bit video has about 250 codelevels per channel, 10-bit video increases that to about 1000 codelevels. HDR not only increases the number of codelevels, but can also improve their efficiency. SDR video is tied to gamma encoding, a system created to compensate for the characteristics of 1950s era cathode ray tube televisions. HDR can replace gamma with approaches better matched to the needs of the human visual system. These include Perceptual Quantization (PQ) and Hybrid Log-Gamma (HLG).

The combination of HDR and 10-bit quantization enables far more accurate rendition of grayscale. SDR tends to oversimplify the grayscale, making objects appear flatter and less lifelike. For content creators and Image Generators, HDR provides a vastly expanded canvas.
on which to create images. For end-users, HDR provides a more immediate, more emotionally compelling experience.

Supple grayscale rendition also helps display key aspects of Renaissance painting. It more faithfully reproduces the chiaroscuro that defines the bulging muscles in Michelangelo’s The Creation of Adam. It more accurately conveys the “sfumato” shading on the face of Mona Lisa. And it more precisely reproduces the delicate play of light on the back wall of so many Vermeer interiors.

The combination of 10-bit grayscale and 4K Ultra HD resolution results in powerful synergies. Expanded grayscale offers a wider range of brightness levels while 4K provides more pixels across which to paint those levels.

![Simulation of HD SDR vs 4K SDR](image1.png)

![Simulation of HD HDR vs 4K HDR](image2.png)

Based on a section of the sky from the previous image, this simulation shows how 4K resolution and HDR go hand-in-hand to create a more organic picture. HDR alone does nothing to improve resolution. 4K alone does nothing to alleviate “banding.” 4K HDR clearly delivers the smoothest, most natural rendition.

**Wide Color Gamut with BT.2020**

Constrained by CRT television phosphors and tube-equipped television cameras, SDTV had a limited range or “gamut” of possible colors. This means that subjects with the deepest, most saturated green, yellow, orange, red and violet appear muted or muddied. This can degrade the reproduction of both natural colors (flowers) and artificial colors (neon lights) as well as other emissive sources (volcanoes, sunsets). The CIE chromaticity chart is a two dimensional plot that shows every visible hue. In RGB reproduction systems, the gamut forms a triangle defined by the Red, Green and Blue primaries at each corner. Surprisingly, the digital SDTV color system occupied a CIE chromaticity triangle that covers only about 36% of visible hues. The International Telecommunication Union standardized this color space as ITU-R BT.601 (called BT.601 or Rec. 601 for short).
Because CRTs were still the dominant display technology during the development of HDTV, the HD color range, Rec.709, was no larger.

![Color Gamut Diagram]

The HDTV color gamut, ITU-R BT.709 (inner triangle) covers only about 36% of visible colors. The Digital Cinema Initiatives P3 gamut (middle triangle) is larger. Ultra HD ITU-R BT.2020 color dwarfs them both, covering about 76% of visible colors.

The development of plasma and OLED flat panel displays plus the availability of LCD displays with a range of backlight technologies have opened up new possibilities in color reproduction. On the digital projection side, new light sources and filters have also enabled superior color. It was to overcome previous limitations and to anticipate future improvements in display technology that the ITU specified a far greater range of color for 4K Ultra HD. The Rec. 2020 standard more than doubles the range of reproducible colors. Compared to SDTV (Rec. 601) and HDTV (Rec. 709), both of which deliver 36% of visible colors, the Rec. 2020 gamut covers 76% of visible colors.

Wide Color Gamut can be a game-changer in professional applications. For art museums, it’s a fundamental transformation in the color palette. For natural history museums and planetariums, it’s new ability to show the natural world with far greater accuracy. For ground combat simulation, it’s a superior ability to distinguish camouflage from foliage. And for flight simulators, it’s far greater realism in the display of runway lights and other emissive light sources.

The CIE chromaticity chart only tells part of the story. It says nothing about reproducing colors across the range from dark to light. To do that, we need to add another dimension, going from color “area” to color “volume.” In terms of color volume, the difference between SDR and HDR is staggering.
Because HDR combines wider color gamut with higher peak brightness, you not only get a wider color area. You also get greater color volume with the vertical axis representing projector brightness. This chart compares a lower-brightness Rec. 709 projector with the VPL-GTX380, which achieves both 10,000 lumens of brightness and 100% coverage of the DCI-P3 color gamut.

**HDR in production and B2B**

We stated at the outset that advances in production technology have made HDR a practical reality. In fact, the current HDR ecosystem extends “from glass to glass” – from the camera lens to the projection lens.

- **HDR cameras.** Modern image sensors in today’s broadcast and digital motion picture cameras are fully capable of supporting HDR.
- **HDR recording systems** such as Sony’s X-OCN® and XAVC® codecs capture HDR with great fidelity.
- **HDR live broadcast infrastructure** includes the switchers and cross-converters to make live HDR sports and entertainment possible.
- **HDR professional monitors** enable color grading and image management. Sony’s legendary TRIMASTER® monitors are the touchstone for HDR picture evaluation in postproduction.
- **HDR industrial video.** As HDR permeates the broadcast and motion picture industries, HDR-capable equipment has become available for every tier of production. HDR is now an attractive option in corporate, educational, government and faith video.
- **HDR televisions** have started to enter American living rooms. According to the Consumer Technology Association, viii 16% of US households had an HDR television, as of 2019.
- **HDR computer graphics** from industry leaders like AMD, Intel and NVIDIA support computer display.
- **HDR Image Processors** for simulation can render color with tremendous subtlety and range.
- **HDR home theater projection.** Sony’s line includes the VPL-VZ1000ES, VW5000ES, VW995ES, VW885ES, VW695ES and VW295ES.
• **HDR movie theater projection.** HDR capable projectors include Sony’s SRX-R815DS and R815P.
• **HDR installation projection.** Of course, Sony supports visualization, simulation, museums, exhibits and attractions with the projectors featured in this white paper, the VPL-GTZ380, GTZ280, GTZ270 and GTZ240.

**The momentum behind HDR content distribution**

With the HDR production ecosystem well established, many content distributors now offer HDR. The same distribution channels that support 4K (described in the first paper in this series) are also supporting HDR. The momentum is palpable.

- **HDR Digital Cinema** is now a part of the Digital Cinema Initiatives (DCI) specification.
- **HDR streaming services** now include Amazon Prime, Apple TV+, Disney+, Netflix and Vudu.
- **Cable and satellite services with HDR content** now include Altice Optimum, Comcast Xfinity X1, DirecTV, Dish, FuboTV and Verizon FiOS. In January 2020, selected systems distributed American football’s biggest game live in 4K HDR. The broadcast gear covering the game included three of Sony’s UHC-8300 8K HDR cameras.
- **HDR over-the-air broadcasting** is now authorized by the FCC as an option in NextGen TV, formerly known as ATSC 3.0.
- **Ultra HD Blu-ray Disc** delivers HDR on physical media.
- **HDR video gaming** is now supported by the PLAYSTATION 4 Pro and Xbox One S consoles.
- **HDR home video** is available from camcorders and still cameras.

As with 4K, HDR is also recognized by a suite of internationally accepted standards.

**HDR support in the Sony GTZ Series projectors**

Sony’s GTZ Series projectors enable your applications to look amazing in High Dynamic Range. The difference is unmistakable. To support HDR, Sony projectors accommodate signals beyond the typical 8 bits of grayscale, supply HDR Electro-Optical Transfer Functions (EOTFs) and accommodate a color space for watching HDR content. As a result of these refinements, the GTZ Series delivers picture quality like no other.

Specifics vary by model. HDR projection on the VPL-GTZ280 requires the LSM-HDR1 license, sold separately.
**HDR brings it all together.**

Projecting HDR well demands the utmost in contrast, resolution, color gamut and grayscale rendition. Sony’s projectors are ready. Thanks to our proprietary SXRD® microdisplay, we already have native 4K resolution, tremendous native contrast and 3-chip color. By adding HDR bit depth, HDR transfer functions and HDR color gamut accommodation, Sony’s GTZ Series projectors deliver a phenomenal improvement in picture quality.

If the SXRD chip is the foundation of Sony’s projection picture quality, **HDR is the capstone.**

**Sony, the video professionals**

In industry after industry, professionals who care about picture quality entrust their work to Sony. Our gear meets the most stringent tests, not only from engineers looking to maximize performance, but also from financial officers looking to maximize return on investment. We deliver the quality, reliability and sustained product life cycles that professionals know and trust.
## Projectors for visualization, simulation and exhibits

<table>
<thead>
<tr>
<th>Model</th>
<th>VPL-GTZ380</th>
<th>VPL-GTZ280</th>
<th>VPL-GTZ270</th>
<th>VPL-GTZ240</th>
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</thead>
<tbody>
<tr>
<td>Panel</td>
<td>0.74” x 3 SXRD</td>
<td>0.74” x 3 SXRD</td>
<td>0.74” x 3 SXRD</td>
<td>0.74” x 3 SXRD</td>
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<td>5,000 lm with optional license</td>
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<tr>
<td>Color brightness</td>
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<td>5,000 lm</td>
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<tr>
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<td>Native 4K (4096 x 2160)</td>
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<td>Up to 20,000:1 *2</td>
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<td>BT.709</td>
<td>Emulated BT.2020</td>
<td>BT.709</td>
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<td>DisplayPort x4</td>
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<td>Input signal</td>
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<td>Up to 4096 x 2160/120P *3</td>
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<td>35 dB *4</td>
<td>39 dB *4</td>
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<td>21-5/8 x 9 x 29-1/2 in.</td>
<td>21-5/8 x 9 x 29-1/2 in.</td>
<td>22 x 8-7/8 x 19-1/2 in.</td>
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<td>Approx. 88 lbs.</td>
<td>Approx. 88 lbs.</td>
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<tr>
<td>Weight (excluding lens)</td>
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<td>40 kg</td>
<td>19.5 kg</td>
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<td>2000 W *5</td>
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<td>-</td>
<td>-</td>
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<td>Weight (excluding lens)</td>
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<td>490 W</td>
<td></td>
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<td>Standard lens: 1.27 – 2.73</td>
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<td>Horizontal</td>
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<td>Standard lens: ±31%</td>
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</table>

*1. Laser output: 100; Lens: New standard zoom; Zoom: wide; H/V Shift: 0
*2. Approximate. Depends on projector settings and usage environment.
*3. Standard is 60P. 120P requires software license, sold separately.
*4. Depends on the environment and how the projector is used.
*5. AC 100 – 120 V can be used with limited brightness.
A final word

In this document, you’ll find a wealth of charts, diagrams and technical explanations. But reading about Sony’s projectors is a poor substitute for hands-on/eyes-on experience. Your Sony representative will be happy to arrange a demonstration.

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iii  https://www.digitaltrends.com/home-theater/what-is-hdr-tv/
iv  https://mytechdecisions.com/video/high-dynamic-range-hdr-4k-uhd/
v  http://carltonbale.com/does-4k-resolution-matter/