Projection Image Quality Series

White Paper #1: Resolution
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Welcome

From data visualization to simulation, planetariums, museums, trade shows and theme park attractions, projection users are demanding higher picture quality. But what is picture 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{i,ii,iii,iv,v} the most important advance in picture quality? And how can today’s installation designers make informed choices?

To answer these questions, Sony has created a series of three white papers:

1. Resolution
2. SXRD\textsuperscript{®} microdisplays
3. High Dynamic Range

These papers will address picture quality from the fundamentals of human vision, through to the production and distribution technologies that bring content to the screen, as well as the projectors themselves.

In this paper, we’ll treat the subject of resolution including how the 4K era is reshaping end-user expectations. We’ll trace developments in television sales, content creation and movie theaters. We’ll explore how the human eye-brain combination perceives detail. We’ll itemize the benefits of higher resolution:

- More information
- Greater realism
- Greater immersion

And we’ll demonstrate how Sony’s projectors empower you to take full advantage.
The triumph of 4K

In 1896, when the Lumière brothers first showed their movie of a train arriving at a station, frightened audience members rose from their seats, ready to jump out of the way. Why do we no longer panic at the movies? Engineer and lecturer Mark Schubinvi has suggested that over a lifetime of viewing screens, we’ve learned how to receive audio/visual content. Viewing A/V is a learned behavior. And right now, your end-users are learning to watch 4K in their living rooms, their movie theaters and their offices.

4K Ultra HD has exactly four times the pixels of 1080p. Digital Cinema 4K is slightly wider.

The Consumer Technology Association organizes the annual CES trade show in Las Vegas and conducts extensive research into consumer electronics purchasing, purchase intent and household penetration. Their surveyvii of 2019 television sales in the United States found that more than 22 million TVs – fully 56% of all TVs sold – had 4K Ultra HD resolution.

In movie theaters, Sony was the leading projector vendor in the historic conversion of US movie screens from film to digital. We achieved greater than 50% market share. And all our cinema projectors are 4K.

In computing, 4K displays have made the transition from exotic to commonplace, with a range of name brand monitors at street prices of less than $500.

And while you adjust to the onrush of 4K displays, TV manufacturers have already debuted high-end models with 8K (7680 x 4320) panels. Your end-users are spending hours and hours with 4K displays in so many aspects of their lives. If audio/visual consumption is a learned
behavior, your users are learning to expect 4K. For systems integrators, planetariums, museums, trade show exhibitors and simulation providers, offering lower resolutions means risking audience disappointment.

Sophisticated readers will know that much entertainment on those 4K screens is currently upscaled from HD (in television) or 2K (in movie theaters). That’s certainly true. But upscaling circuits like Sony’s own Reality Creation 4K processor (in the GTZ series projectors) achieve remarkably satisfying results. And even if your content is currently Full HD, 2K or WUXGA, it could easily migrate to 4K during the life of the projectors you specify today. 4K projectors prepare you for the movement to 4K content, which is happening faster than many observers realize.

The momentum behind 4K content

Native 4K entertainment content is making great strides in consumer distribution channels.

- **4K Digital Cinema** content has been available for more than ten years. A range of digital motion picture cameras from Sony and others capture with 4K or 6K resolution. Some cameras even offer 8K.
- **4K streaming services** now include Amazon Prime, Apple TV+, Disney+, Netflix and Vudu.
- **Cable and satellite services with 4K 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. The broadcast gear covering the game included three of Sony’s UHC-8300 8K cameras.
- **4K over-the-air broadcasting** has now started in the US. The FCC has authorized 4K as an option in NextGen TV, formerly known as ATSC 3.0.
- **Ultra HD Blu-ray Disc** delivers 4K content on physical media.
- **4K video gaming** is now supported by the PLAYSTATION 4 Pro and Xbox One S consoles.
- **4K home video** is available from camcorders, still cameras and even cellphones.

To support these developments, 4K is recognized by internationally accepted standards, including the International Telecommunication Union’s ITU-R BT.2020 recommendation and the corresponding Society of Motion Picture and Television Engineers standard SMPTE ST 2036-1. In the movie theater, 4K is enshrined in the Digital Cinema Initiatives (DCI) specification. 4K Ultra HD is also supported by the Consumer Technology Association, the Blu-Ray Disc Association, the UHD Alliance, High-Definition Multimedia Interface (HDMI) Founders and the ATSC 3.0 TV broadcast standard.

**4K in corporate video production and display**

With 4K ascendant in broadcast, movie production and consumer camcorders, it’s no surprise that 4K is also becoming a mainstay of corporate video. 4K cameras of all shapes and sizes are now common in video production for businesses, government agencies, houses of worship and schools. And just as 4K dominates the market for large screen television, 4K is now prominent in public displays for lobbies, lecture halls, meeting rooms and huddle spaces. That’s no surprise. Many public displays incorporate the same LCD panels as consumer TVs.
4K in visualization, simulation and dome projection

Over the years, CPUs, GPUs, graphics cards and display interfaces have all made impressive strides. As a result, 4K is now an established computer display standard. And we’ve seen that 4K computer displays are now available from multiple vendors for less than $500. This evolution has naturally had an impact in dome projection, where off-the-shelf tools for 4K warping and blending are well established and 4K projectors are becoming the de facto standard.

In simulation, the mission-critical quest for realism has led to such visual refinements as particle-based clouds, dynamic shadows, airport clutter and 3D ship wakes. In this context, 4K resolution adds yet another degree of realism, and is supported by Image Generators including the Bohemia Interactive Simulations VBS Blue IG, Diamond Visionics Genesis IG, MetaVR VRSG, Quantum3D Independence IDX8000 and IDX80, and the VIRES Simulationstechnologie v-IG.

4K means more information.

Sometimes there’s no substitute for pixels. Whether your end-users are searching for oil deposits, examining fine art or training for air-to-air combat, more pixels mean more information. 4K projection is a better way to display details, be they paint strokes intended for close examination or distant bogeys demanding rapid response.

If your application requires detail, 4K presents four times as much detail as 1080p HD
4K enables a more lifelike picture.

Having four times the pixels of Full HD delivers another benefit. As you step back from the screen, 4K contributes to a smoother, more lifelike image. The visibility of pixels or “jaggies” on diagonal subjects goes away. And the image becomes more seamless and satisfying.

If your application requires realism, 4K pixels can be 1/4 the size of 1080p pixels.

4K enables greater immersion.

With four times as many pixels as Full HD, 4K enables your end-users to sit much closer to the screen before individual pixels become visible. As users sit closer, the picture occupies a wider angle of view and they become more “immersed” in the image. This immersion is a powerful advantage for data visualization, flight simulators, combat simulators, planetariums, museums, multimedia art, tradeshows exhibits and theme park rides.

Calculating the threshold distance

To quantify the greater immersion of 4K, we can calculate seating distances and angles of view. We start with the basic measure of human visual acuity. While different researchers have different descriptions of visual acuity, video engineers have long considered the smallest observable detail to be 1/60 degree of visual angle. VIII This means that to deliver a visually seamless picture, installations should provide a minimum of 60 pixels per degree of visual angle.

If we know the pixel count of a projection system and we have our 60 pixels per degree yardstick, we can use high school trigonometry to calculate the threshold seating distance, the distance at which individual pixels will merge into a seamless image. While we could calculate the threshold for a given screen size, it’s more useful to have some measure that will work for screens of any size. That’s why we calculate the distance as a multiple of Picture Height (PH).

- **1080p HDTV** conveys 1920 x 1080 pixels. The threshold distance is about IX 3.2 PH.
- **4K** presents pixel counts of 4096 x 2160 in a 17:9 container for digital cinema or 3840 x 2160 in 16:9 aspect ratio for Ultra HD television. For either version, the 4K threshold distance is half that of 1080p. It’s now just 1.6 PH.
If your application requires immersion, 4K enables a shorter viewing distance, as measured in Picture Heights. The screen can occupy a much wider field of view without pixels becoming visible.

These calculated threshold distances match the numbers provided by the International Telecommunication Union in Recommendation ITU-R BT.2022. However, the threshold distance is not necessarily the recommended seating distance for all applications. In the context of entertainment, the 4K picture at 1.6 PH is extremely powerful.

The closer you sit, the larger the horizontal angle of vision that the screen occupies. When viewed from the threshold distance, 1080p occupies a 31° angle of view. In comparison, 4K occupies a 58° angle of view, enabling tremendous viewer immersion for those applications that can benefit. Incidentally, the 58° angle of view is near the “sweet spot” in entertainment viewing, according to tests by the Science & Technology Research Laboratories of NHK, Japan’s national broadcaster.

**4K matches the immersive trend in TV viewing.**

The concept of greater immersion via wider angles of view is not simply a matter of pixels and trigonometry. It’s also borne out by viewer behavior. Consumers are voting with their dollars for more immersive experiences. According to the CTA, the average screen size of TVs purchased in the US was 37” diagonal in 2007. By 2019, it had leapt to 48”. Since this average includes TVs intended for bedrooms and kitchens, we can suppose that the average newly purchased living room TV is larger still. A 2019 CTA survey found that 25% of US households had TVs of 60 – 69 inches and 3% had TVs of 70 inches and up. We will consider a 65” TV as “representative” of these households.
Between 2007 and 2019, the average TV sold in the US grew in size by about 30%. If we don’t believe that the average living room grew by 30% during those years, we can infer that the horizontal angle of view occupied by televisions is growing as well. As TVs get bigger and bigger, they occupy larger and larger horizontal angles. This is an enormous change in everyday viewing experiences – and it raises the expectations of your end-users, whether your business is exhibits, simulation or visualization. When your end-users experience spectacular image presentation at home, they won’t accept second-rate performance in your application.

**4K matches the immersive trend in movie theaters.**

The growing immersion in home television viewing parallels the entertainment venue that competes with television – the movie theater. Historically, movie theater design has gone from a maximum recommended distance of 8 PH in the 1940s\textsuperscript{14} to 3.45 PH in 1994\textsuperscript{15}, to an actual measure of less than 3 PH for the back row of today’s stadium seating auditoriums. The closest seats are now less than one Picture Height away.

Contemporary stadium seating auditoriums bring the movie audience quite close to the screen.
4K enables you to strike a better balance.

4K resolution empowers installation designers to establish a better balance between immersion and picture smoothness, optimized for each specific application. It’s much like a ticketholder entering an empty movie theater and choosing their own tradeoff between immersion (sitting toward the front) and smoothness (toward the back).

To optimize your use of 4K in professional projector installations, it helps to review the research on human visual acuity. In this paper, we’ve used the common rule of thumb: 60 pixels per degree, which is equivalent to 30 dark-to-light cycles per degree or 30 line pairs per degree. 60 pixels per degree has two big advantages as a guideline. First, it’s been the yardstick for video engineers for decades. Second, it corresponds to 20/20 vision, with the pixel size matching the smallest details on the 20/20 line of the Snellen eye chart.\textsuperscript{xvi} (20/20 is referenced to feet. Outside the United States, this is 6/6, referenced to meters.)

However, the human visual system is not so simple. Our ability to detect misalignments, called “Vernier acuity” is an order of magnitude better than 60 pixels per degree. The angular diameter of stars in the night sky can be just 1/60,000 degree. Yet their intense brightness makes them visible to the naked eye.

Different researchers have found a range of values for visual acuity.

- **44 pixels per degree.** Detail that humans can "reliably" see.\textsuperscript{xvii}
- **58 pixels per degree.** Detail that humans can "clearly" see.\textsuperscript{xviii}
- **Over 130 pixels per degree.** A controlled study\textsuperscript{xix} at Ewha Womans University in South Korea concluded that a television presenting about 260 pixels per degree had higher perceived picture quality than a television presenting 130 pixels per degree.
- **Over 156 pixels per degree.** Researchers at NHK\textsuperscript{xx} achieved similar results, reporting that viewers can distinguish between pictures that present 156 and 312 pixels per degree.

The last two studies, designed to test the effect of higher-than-HD resolution, suggest that even viewers sitting further than the HDTV threshold distance of 3.2 Picture Heights can still benefit from the picture smoothness advantage of 4K.

In a separate study,\textsuperscript{xxi} NHK asked real-world viewers to score the subjective effect of a range of screen sizes and screen horizontal angular size. NHK found that as the screen occupies larger horizontal angles (sitting closer), the subjective degree of “potency” increases. But as the screen goes beyond 60\degree, degree of “comfortableness” drops off.

\textit{NHK research findings on degree of “potency” and “comfortableness” across different horizontal viewing angles.}
Based on these research findings, we can provide some general guidelines for 4K installations. The following chart rates the subjective effects of 4K at various viewing distances on a five-point scale.

<table>
<thead>
<tr>
<th>4K viewing distance</th>
<th>4K Screen horizontal angular size</th>
<th>Subjective Effect</th>
<th>Smoothness</th>
<th>Viewing Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 0.8 PH</td>
<td>More than 96°</td>
<td>■■■■■</td>
<td>■□□□□</td>
<td>■□□□□□□□</td>
</tr>
<tr>
<td>0.8 to less than 1.6 PH</td>
<td>96° to more than 58°</td>
<td>■■■■■</td>
<td>■□□□□</td>
<td>■□□□□□□□</td>
</tr>
<tr>
<td>1.6 PH</td>
<td>58°</td>
<td>■■■■■</td>
<td>■□□□□</td>
<td>■□□□□□□□</td>
</tr>
<tr>
<td>More than 1.6 to 3.2 PH</td>
<td>Less than 58° to 31°</td>
<td>■■■■■</td>
<td>■□□□□</td>
<td>■□□□□□□□</td>
</tr>
<tr>
<td>More than 3.2 PH</td>
<td>Less than 31°</td>
<td>■□□□□</td>
<td>■□□□□</td>
<td>■□□□□□□□</td>
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</tbody>
</table>

Other aspects of resolution

We’ve seen that 4K can deliver more information, a more lifelike picture and greater immersion. But that’s not the end of the story. For one thing, not all “4K” projectors have the same native resolution. For another, pixels alone do not fully account for what we perceive as sharp pictures. Contrast and frame rates also play a part.

True 4K, not “faux K”

Enabled by Sony’s proprietary SXRD® technology, our GTZ Series projectors incorporate three microdisplays, each with native 4096 x 2160 resolution. This means you get a true 4K picture with full image integrity. There’s no pixel shifting, no interlacing. The same cannot be said for projectors that have 4K inputs but must somehow downconvert the signal because they don’t have native 4K microdisplays. Dubbed “faux K” by some observers, these projectors may claim “4K-ness.” But in a design reminiscent of interlace scanning, these projectors typically divide the image into “A” and “B” sub-frames. A mechanical actuator then shifts the image by half a pixel to project each sub-frame. By this technique, vendors can double the number of “display pixels” without increasing the native resolution of microdisplays themselves. Of course, this also means that you’re only seeing half the pixels at any given instant. You can identify these “faux K” projectors by taking a close look at the specifications. If the manufacturer claims more “display pixels” than the native pixel count of the projection chips, then you’re looking at pixel-shifting. You can’t expect “faux K” to deliver same performance as native 4K. And it doesn’t.

We input test images of alternating white and black stripes one pixel wide, plus a one-pixel checkerboard to one of our 4K projectors and three pixel-shifting competitors with native 1080p chips. These are all projectors from major global brands that can input 4K and thereby make some claim of “4K-ness.” Then we took high-resolution still images of the projected results. It’s no surprise that the Sony projector reproduces the test patterns faithfully, a feat the other projectors can’t match.
We then repeated the tests with the same projectors and test signals that are two pixels wide, and checkerboard squares that are 2x2 pixels, adding diagonal stripe test patterns for good measure. Even here, on these much less demanding tests, the other projectors had issues.

Some projectors generate a quasi-4K picture from microdisplays with native resolutions such as 2716 x 1528 or 2560 x 1600. Even these projectors can only present half of the 4K pixels at any given instant. In addition, several of these projectors are limited by one-chip color reproduction. As we will see in the next paper in our series, one-chip systems can only generate one color at a time. These one-chip projectors cannot display all the pixels – or all the colors – all the time.

The simple fact remains: to project a true 4K image, you need a true 4K projector. While pixel-shifting “faux 4K” projectors may provide 4K inputs, they are simply not capable of persistent 4K presentation.

Contrast and sharpness

If you’ve read this far, you may be forgiven for inferring that resolution is the king of projector specifications. Or that native 4K resolution by itself guarantees picture quality. While undoubtedly important, resolution is just part of the picture. In fact, resolution is quite different
from the human perception of sharpness. In order to deliver sharpness, you need both resolution and contrast. This was established in 1948 by Otto Schade at RCA Laboratories, who applied the concept of the Modulation Transfer Function (MTF)\textsuperscript{xxii} to television systems.

We can diagram MTF by putting modulation (contrast) on the vertical axis and spatial frequency (resolution) on the horizontal. Schade recognized that achieving the highest possible maximum resolution made little impact on perceived sharpness at TV and movie viewing distances. What mattered most was not the last little shreds of resolution, but the area under the MTF curve. Contrast alone is not enough. Resolution alone is not enough. You need to have both.

Importantly for all subsequent imaging research, MTF has become the “common coin” of image analysis, applying equally to television and film, and useful in describing lenses, image sensors, film emulsions, recording systems, transmission systems and displays.

Here are two MTF curves for theoretical imaging systems. The one on the left exceeds 8K resolution – however at very low contrast. Even though it has lower maximum resolution, the system on the right has higher contrast and a larger area under the curve. This would look much sharper.

Working together, the combination of high resolution and high contrast has a powerful effect on perceived image quality. Resolution and contrast enable picture details to “pop,” becoming dramatically crisper and more lifelike.
Installers and professionals know that apples-to-apples comparison of contrast ratio specs from different manufacturers can be challenging. Even so, Sony’s GTZ Series projectors deliver superlative contrast, in many cases visibly superior to alternatives. With Sony, you get more than 4K resolution. You get the added impact of 4K sharpness.

**Temporal resolution: High Frame Rates**

4K represents an advance in “spatial resolution” – detail across the face of the picture. High Frame Rates represent an advance in “temporal resolution” – detail across time. In video systems, progressive scanning 1080/60p delivers twice the information of 1080/60i, while 4K/60p delivers eight times. That’s a substantial advantage in combat simulators, flight simulators, science museum exhibits and sports video – any application where clear rendering of fast motion is a priority. Computer-generated images in particular benefit from high frame rates, often referred to as refresh rates. If the computing resources are available, high frame rates contribute to much more powerful simulations. All Sony’s GTZ Series projectors support 4K/60p projection. The VPL-GTZ280 supports 4K/120p with the LSM-120P1 license, sold separately.

*Higher frame rates can render motion with more intermediate steps, helping reduce motion blur. In the enlarged images at left, you can see that the black grid pattern on the soccer ball is far clearer at 120 fps.*

The choice of frame rates depends on application. Many movie directors and cinematographers consider High Frame Rates “too real.” They prefer the traditional movie rate of 24 frames per second as more “cinematic” and more appropriate for fiction.
Introduced in 2015, Sony's Emmy® Award winning HDC-4300 became an instant hit with sports broadcasters by combining HFR and 4K Ultra HD together with the ability to accept standard broadcast lenses.

Sony and 4K

Sony has been a leader in 4K since 2005, when we launched the world’s first commercial 4K projectors, the SRX-R110 and R105. We also built the world’s first 4K projector dedicated to Digital Cinema, as well as the world’s first 4K projector for the home. All of these testify to Sony’s unwavering focus on projection technology. And all of them were made possible by Sony's proprietary Silicon X-tal Reflective Display (SXRD®) projection chips, the subject of the second paper in this series. While most other projector brands must order microdisplays from third-party suppliers, Sony designs and manufactures our own chips.

And projection is just a part of Sony's leadership in 4K. Our scope extends from motion picture and broadcast cameras to professional monitors, instant replay servers and broadcast switchers. Our 4K consumer products include BRAVIA® televisions, camcorders, our landmark Alpha mirrorless cameras and the PLAYSTATION® 4 computer entertainment system.

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

VPL-GTZ280
4K SXRD laser projector with 2,000 lumens output (up to 5,000 lumens with optional license) and accurate reproduction of high-speed motion for simulations

VPL-GTZ270
4K SXRD laser projector with 5,000 lumens light output and superb image quality

VPL-GTZ240
4K SXRD compact laser projector with 2,000 lumens output and accurate reproduction of high-speed motion

The future
Stay tuned for further developments.

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.


iii  https://www.digitaltrends.com/home-theater/what-is-hdr-tv/

iv  https://mytechedcisions.com/video/high-dynamic-range-hdr-4k-uhd/

v  http://carltonbale.com/does-4k-resolution-matter/


vii  CTA Research, reported January 2020


ix  Picture Height calculations can yield a false sense of precision. For flat screens, the threshold distance varies from screen center to screen corners. And in his SMPTE NY Chapter presentation, cited above, Mark Schubin points out that even in a fixed seating position, a real person can lean forward or back.


xii  CTA Research, reported January 2020

xiii  CTA Study 2019: “Consumer Technology Ownership and Market Potential”


xv  According to engineering guideline SMPTE EG 18-1994, since withdrawn

xvi  http://webvision.med.utah.edu/KallSpatial.html

xvii  Schubin, Mark, “High and Why,” Digital TV, October 2004


xx  Cited in Schubin, Mark, “The Future of Videography (All in One Place),” Videography, July 2008
