SONY

CRYSTAL LED FOR VIRTUAL PRODUCTION

WHITE PAPER

1. Introduction

Accelerated in part by needs created by the pandemic, motion picture and television crews have witnessed the rapid adoption of virtual production and in-camera VFX techniques.

Virtual production uses technology to join the virtual world with the physical world in real-time. It enables filmmakers to interact with a digital process in the same way they interact with live-action production in real-time. The benefits are clear: improvements to workflow efficiencies, while also providing more creative options. But what is virtual production? The term virtual production is broadly used to describe a wide range of production workflows leveraging computer-aided filmmaking tools, such as: world capture (asset scanning and digitization), photo-realistic real-time rendering including previsualization, performance capture (motion and volumetric capture), simulcam (on-set visualization), and, most recognizably, in-camera visual effects (ICVFX).

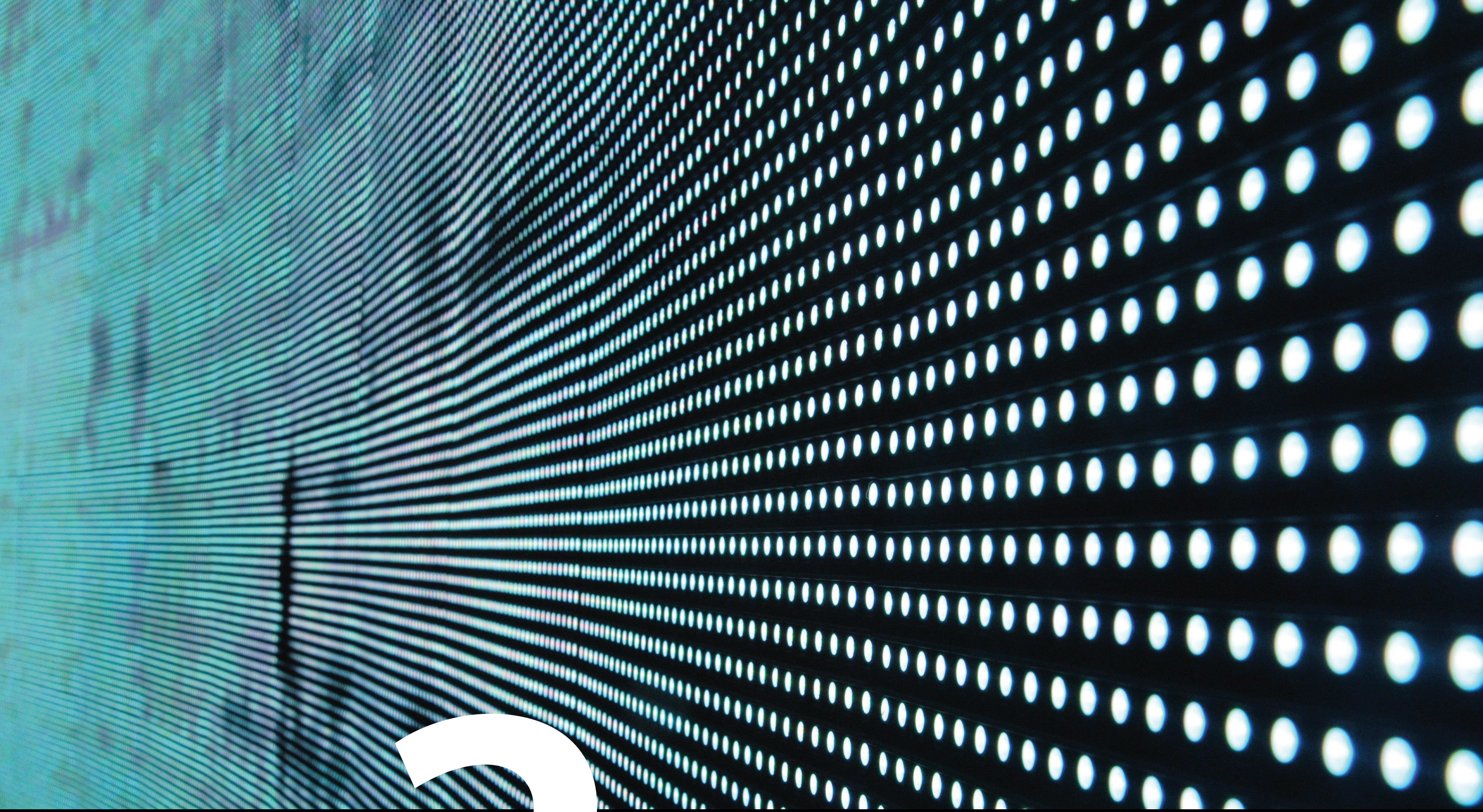
For the purposes of this white paper we will focus on ICVFX. ICFVX is the process of capturing visual effects live and in-camera on set, such as within an LED volume. This can be thought of as simply a workflow in which traditional green screen stages are replaced with LED displays to capture visual effects in camera and in real-time. During ICVFX, game-engine technology is used to render background images on LED walls while the camera captures the total, composited scene. Scenes that previously may have taken hundreds of hours to compose, shoot, render and composite might now be accomplished in real-time, in-camera and onset. Remarkably, in-camera visual effects can work when capturing both 3D worlds, as in the case of Disney's The Mandalorian, or with 2D plates, such as in a driving sequence. In addition to the ability to shoot multiple complex scenes efficiently on a single set, ICVFX offers efficiency in other areas, such as capturing environmental lighting and reflections in real-time — thereby reducing the need for postproduction compositing which is needed with green screen productions.

As with any revolutionary new production process, there are several technical aspects of the ICVFX workflow that require further evaluation and technical analysis. The final "look" of the virtual production is impacted by the interaction between the selected LED display performance, the selected cinema camera, especially lens and sensor characteristics, along with the real-time rendering engine, motion tracking systems and stage lighting.

Sony VENICE in front of EPIC Games' testing facility

To understand how these interactions impact virtual production, Sony Electronics partnered with EPIC Games and other industry experts on a series of tests. The tests were aimed at gaining a better understanding of the impact of these system-wide performance attributes and to evaluate how these parameters affect the quality and workflow of virtual production (https://youtu.be/hG8VWdynZIA). For this study, we benchmarked the Crystal LED "B-series" display, a fine-pitch, high-quality LED system custom designed for virtual production and co-developed by Sony Electronics and Sony Pictures Entertainment. Our test results provided valuable insight into how systems can be designed to limit undesirable results like **Moiré pattern visibility, poor black level performance**, and **off-axis color shift**.

In this white paper, we will review these factors and explore their potential impact on the finished product and compare the performance of Crystal LED with other popular LED display products.



2. LED Display Basics

Let’s start with a brief overview of display technology used for virtual production volumes. Direct-view LED (light-emitting diode) displays are constructed from a dense matrix of pixels, each incorporating an individual red, green and blue (RGB) LED emitter.

For displays found in virtual production volumes, the spacing between pixels, referred to as the pixel pitch, is typically between 1mm and 4mm. Since fine pixel pitch displays are more costly on a per-area basis (cost per square meter or square foot), larger pixel pitch units are often used for less-demanding floor or ceiling portions of the volume or for background plates in very large stages. On the other hand, smaller stages, such as those roughly 26 ft (8 m) or less in width, require finer pixel pitch, typically in the 1.25mm to 2.5mm range, to avoid individual pixels being visible on camera at typical shooting distances.

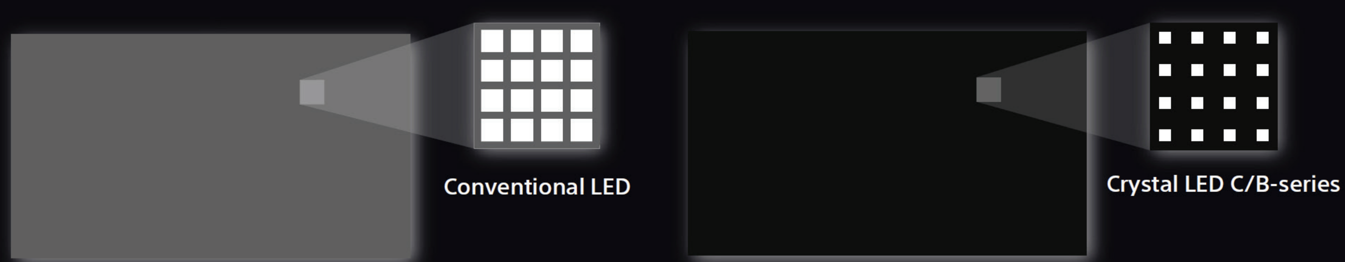
The LED pixels are fabricated on a substrate within cabinets to create the LED display. The cabinets are mounted side-by-side and top to bottom in sturdy structural frames and carefully aligned to avoid visible seams or gaps. The frame can be flat on a virtual production stage, but it is often engineered to form a concave curve surrounding the set area. The video image is fed through a game engine, such as EPIC Games' Unreal Engine, and segmented and distributed to the many LED cabinets from one or more LED image processors.

In the modern world, LED technology is now commonplace in Vfx driven projects. Standard LEDs consist of a semiconductor light source, measuring roughly 1 millimeter across and emitting light of a defined wavelength (color) when a current flows. For fine pixel pitch LED displays, mini-LED technology is used, with LED chips as small as 200 microns across. For even higher-density fine pitch displays, LED chips are now available, with chip sizes as small as 20 to 100 microns in size. These enable high-definition images even on modest-size panels. These "standard" (or inorganic) LEDs differ in performance and behavior from organic LEDs (OLED) and liquid crystal displays (LCD). Mini-LED and LED technology is uniquely suited for virtual production due to its excellent contrast ratios, color reproduction, wide viewing angle, high brightness, consistent performance, and long life.

For our evaluation, we used the Sony Crystal LED B-series system, which uses LED pixels configured in a pixel pitch of 1.26mm or 1.58mm. The Crystal LED has a unique implementation in that the LED emitters are extremely small in relation to the separation between pixels. This results in significantly more display surface as black substrate, with the light emissions from pixels occupying just a fraction of the screen area. The unique coating applied to the Crystal LED surface allows for the smaller diodes to fill in spaces between pixels, granting the benefit of both higher-contrast as well as better moire performance.

Over the past two decades, LED displays have continued to evolve with improved picture quality, finer pixel pitch, and lower cost. Most of these LED walls are used for signage in corporate boardrooms, retail displays, or even motion picture theaters. And within the past few years, LED displays have also been adopted for critical viewing applications such as high-end production screening rooms, collaborative design centers, and photogrammetry and data analysis suites.

While LED displays have been adopted for a variety of uses, the performance requirements for LED displays used for ICVFX differ from these other uses. Of particular interest are the displays' reflectivity of ambient light off the display surface, their ability for low-level greyscale representation and color accuracy, especially those that offer consistency when viewed from both on-axis and an oblique angle, and other features.



Simulated images

No distinct image

Perfectly distinct image

Ambient Light Reflectivity

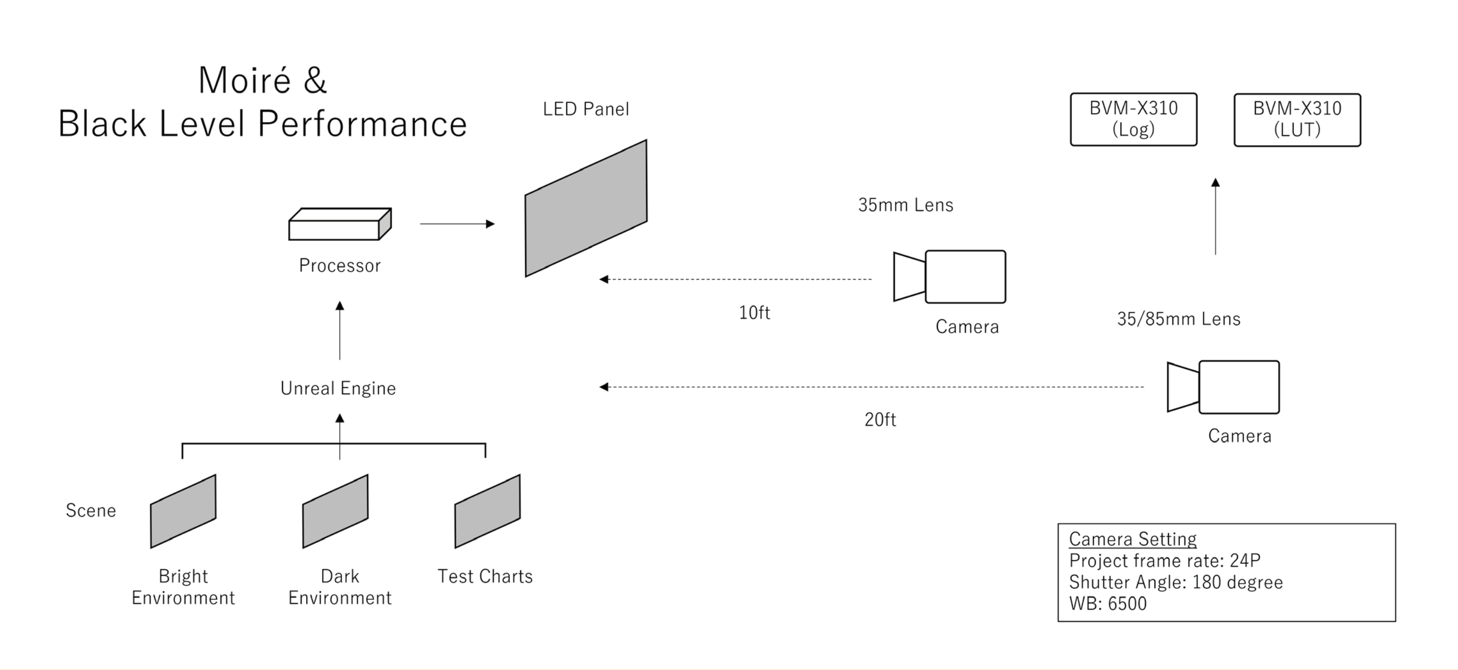
A typical studio environment will, by its nature, include a significant level of ambient light from studio luminaires and on-set practical lights. In order to avoid specular reflections, flare, or washed-out contrast, it is important that the LED display surface reflect ambient light diffusely, minimizing the specular component that arrives back into the camera as much as possible. While Sony's other product in this family, the C-series model, maintains a higher specular reflectivity rating to improve black level performance and contrast ratio, the B-series display was designed to mitigate specular reflections. For comparison, when using a Distinctness of Image (DOI) measurement, the B-series display measures "0" which represents almost no specular reflection of light.

3. Display Evaluations

While understanding the theoretical background of the interaction between the display and camera is important, on-set testing is crucial to ensure footage is free of artifacts that will require correction after principal photography, mitigating potential gains from capturing final-pixel on set.

What follows is a walkthrough of our test procedures and results, in the hopes that it will provide helpful guidelines to those undertaking these tasks in the future.

In the first two tests, the following test setup was utilized, enabling testing at two distinct shooting distances and with two different lens choices.



Moiré Visibility

Moiré is an undesirable interference pattern caused by the interaction between similar patterns that are overlaid on each other. In the case of virtual production, we are combining a cinema camera featuring a sensor arranged in a Bayer pattern with an LED display which features diodes arranged in a similar grid. The relationship between the pixel pitch, density of camera sensor photosites, shooting distance, lens focal length and depth of field all influence whether Moiré patterns become visible in the shot.

To subjectively evaluate Moiré visibility of the Sony Crystal LED display (1.26mm pixel pitch), as compared with another typical LED display used for virtual production (2.8mm pixel pitch), we shot several test images from a distance of 10 feet and 20 feet, and racked focus through the screen plane, observing when Moiré became visible. For this comparison, we use both a Sony VENICE 6K cinema camera with a full-frame CMOS sensor and another popular cinema camera, also fitted with a similar full-frame CMOS sensor.

Due to the finer pixel pitch and unique emitter behavior of the Sony LED display, we found that Moiré patterns were less visible in almost all cases. De-focusing the camera by using a narrower depth of field may also help reduce moiré visibility, but at the expense of limiting creative choices. Other factors, such as the design of the optical low pass filter (OLPF) in the camera will also influence the Moiré visibility and so should be a consideration when selecting the best solution for a particular production.

Moire comparison

VENICE & Crystal LED 10ft shooting distance

- Moire noticeable in narrow focal range

VENICE & 2.8mm LED 10ft shooting distance

- Moire noticeable in wider focal range

Competing Full-frame Cinema Camera & Crystal LED

10ft shooting distance

- Moire: very noticeable through full focal range

Competing Full-frame Cinema Camera & 2.8mm LED

10ft shooting distance

- Moire: very noticeable from infinity though almost full focal range

Black Level Performance: Black Crush and Banding

LED display systems typically use pulse width modulation (PWM) to drive the amount of light emitted from each RGB sub-pixel. With PWM, shorter pulse widths mean that an LED emits light a lower percentage of the time, and therefore appears darker. In a typical LED display found in virtual production stages, the lowest achievable gray level is limited by the minimum PWM pulse width. The result is that reproduction of very low light levels, which often represents shadow details, are “crushed.” This typically happens below some floor – often in the range of 0.01 to 0.02 cd/m2 (nits), below which all LED pixels are turned completely off, displaying only black. The Sony Crystal LED is able to avoid this problem by modulating the LED emissions to reach much lower black level reproductions, resulting in a very low first step out of black and a contrast ratio of over 1,000,000:1.

Banding is an artifact that appears in areas of a color gradient where the lack of sufficient color resolution causes noticeable bands instead of a smooth transition. Banding artifacts occur when there is insufficient bit depth to encode each incremental brightness increase. The result is visible transitions or “bands” in the gradient, which can be very noticeable on-camera. The Sony Crystal LED system utilizes a 22-bit internal processing pipeline, which has proven more than adequate for eliminating banding artifacts in typical virtual production environments. Of course, care must be taken to maintain the high bit-depth signal path throughout the signal chain from the source renderer through image processing to the display to avoid introducing any banding artifacts.

VENICE ×
“Dark Scene” VENICE combined with the following

2.8mm LED | 1.5mm LED | **CLED**

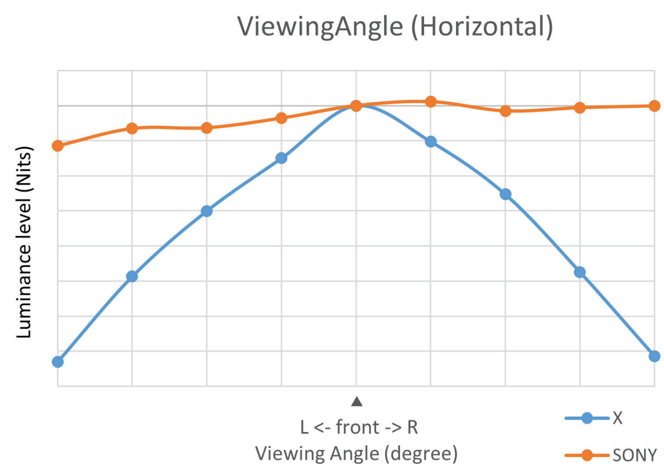
CLED provides better expression in low gradation

Angular Response: Off-Angle Luminance and Color Shift

The nature of LED pixels includes anisotropic emissions. That's just a fancy way to say that the light viewed directly from the front of a pixel display will change as you move off-axis.

Due to the characteristics of the LED semiconductor, the luminance (or brightness) of pixels will vary depending on the viewing position. In a typical virtual production LED display, the brightness level will decrease by approximately 50% as the viewing angle is shifted to 60 degrees off-axis, compared to viewing from directly in front of the display. However, the use of very small diodes in the Crystal LED display, combined with the unique way these LEDs are mounted to the substrate, results in extremely uniform brightness when viewed from almost any horizontal angle.

Similarly, color rendition will also shift with viewing angle on typical LED displays. This is often observed as a magenta to cyan shift across a range of viewing angles, when displaying a flat white image on an LED display. The Sony Crystal LED display effectively minimizes the color offset due to the small pixel size and spacing.



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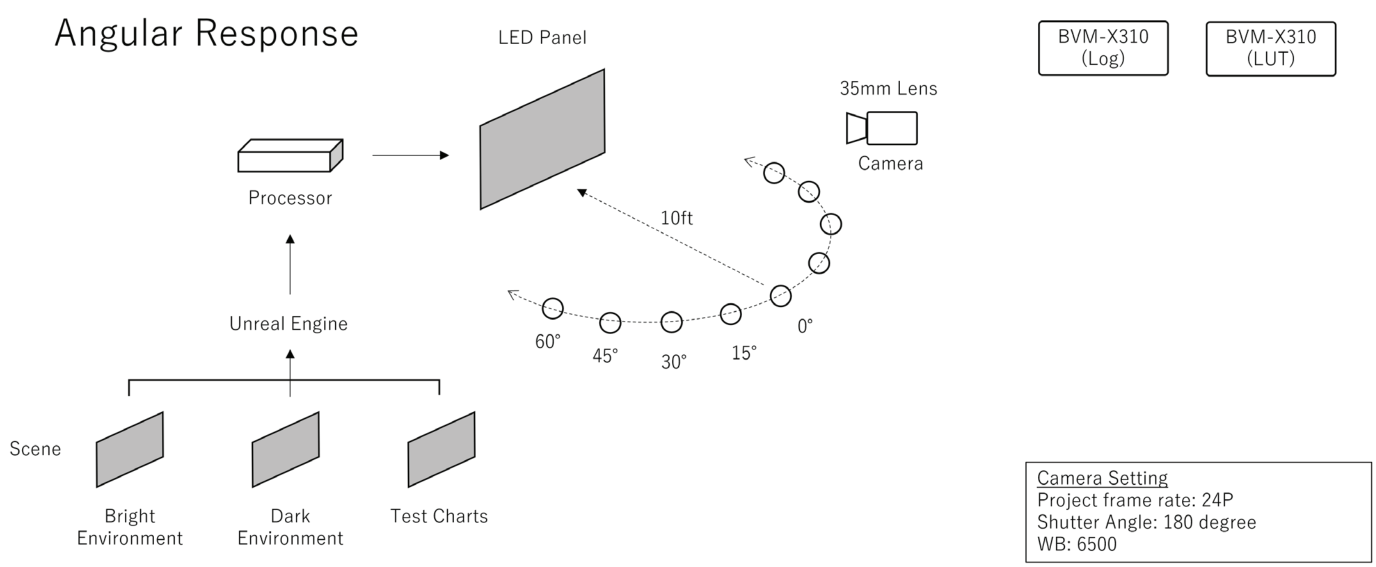
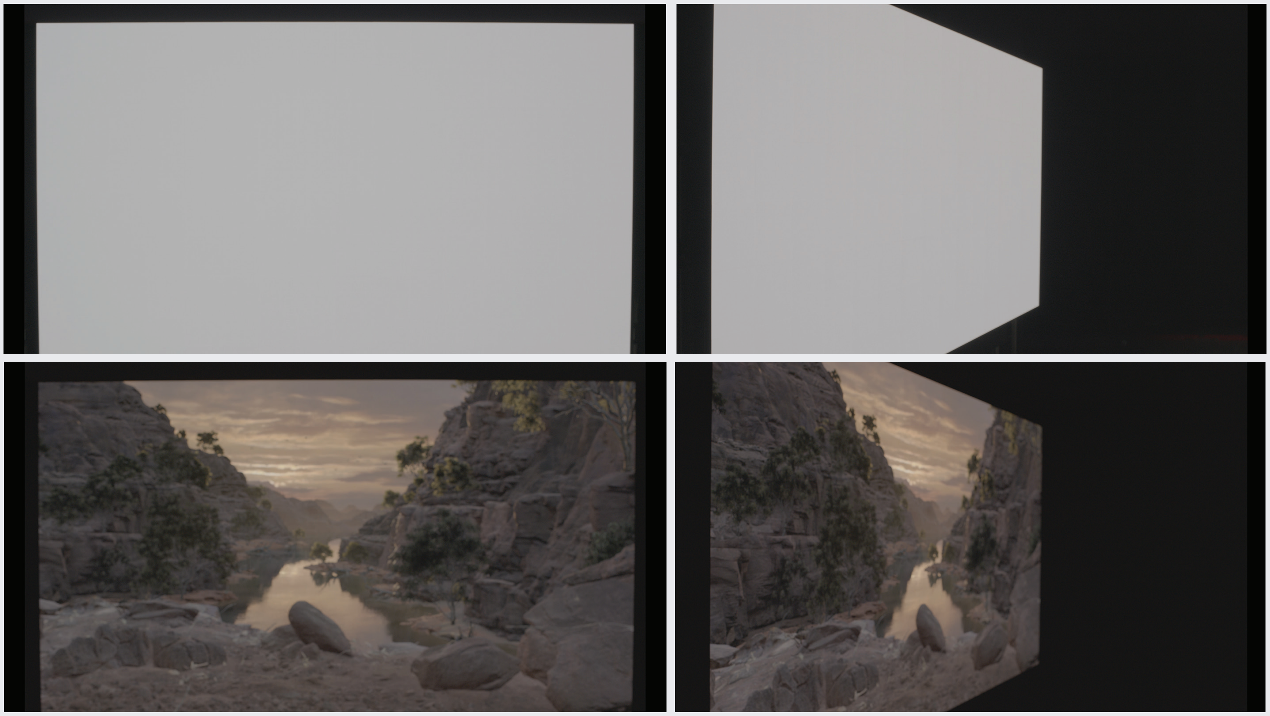
The ability to capture the LED background images at sharp angles to the camera axis, without worry of color errors, will help remove shooting constraints during production and allow more of the LED volume space to be utilized.

For testing with off-axis performance, a camera dolly and track were used to replicate the same test procedure for multiple displays. Markers were recorded and specific camera angles to the display so that the footage could later be evaluated directly between the different technology combinations.



VENICE & Crystal LED Angular Response

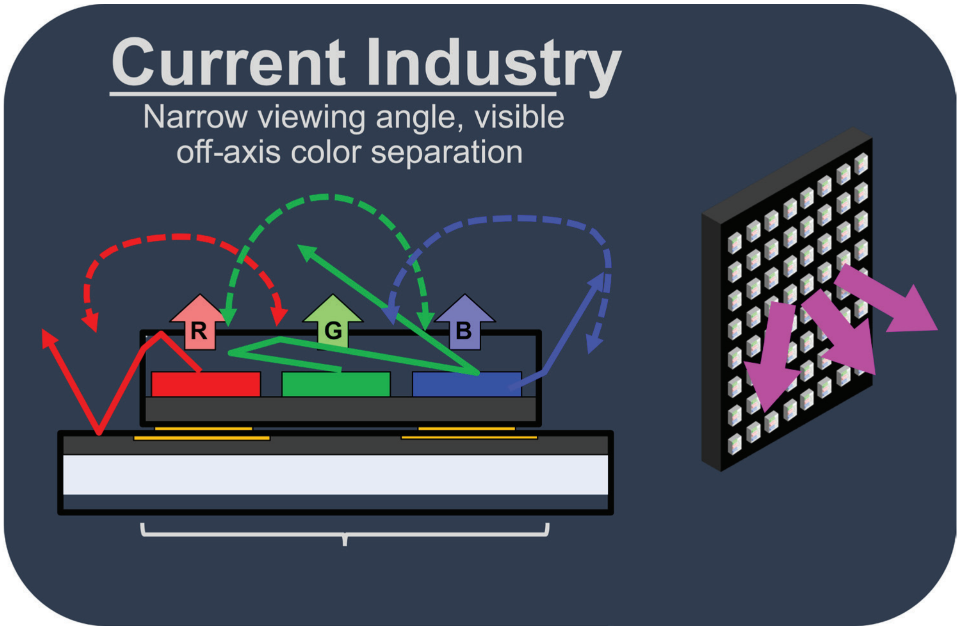


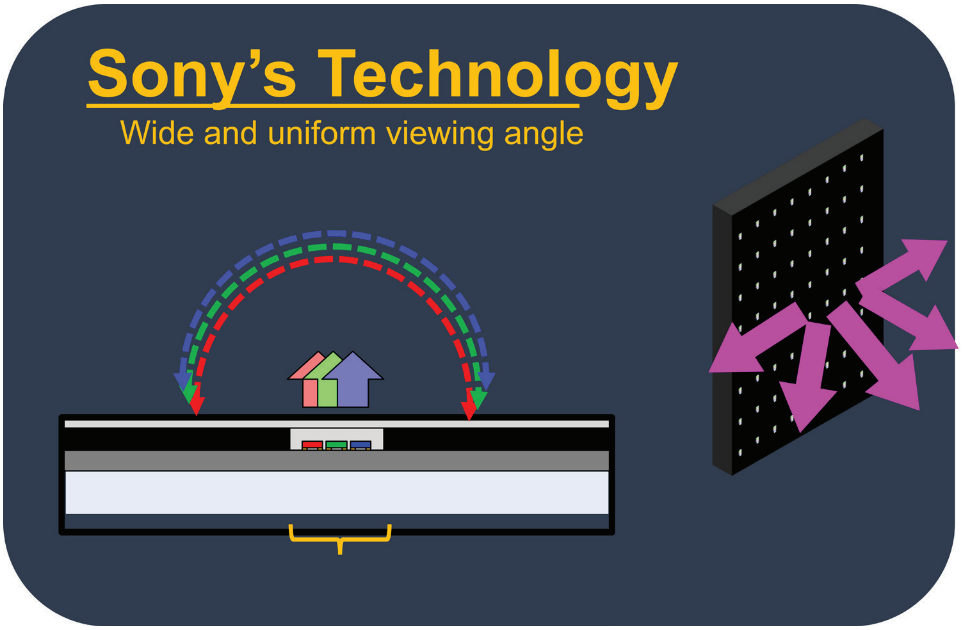
0 vs 45-degree off-access performance. Color shift is difficult to perceive in footage.

VENICE & Industry Standard LED

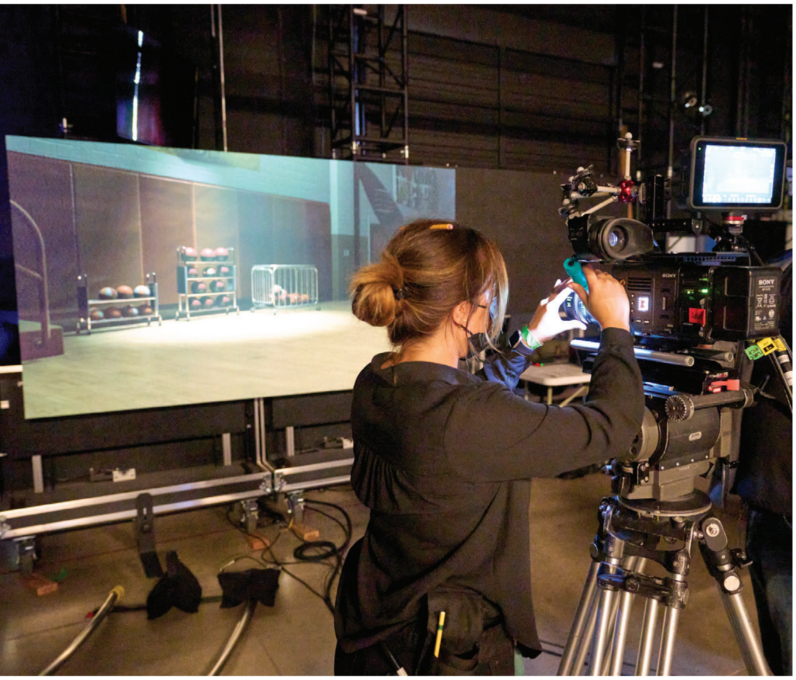
0 vs 45-degree off-access performance. Color shift is noticeable in footage but difficult to perceive in photos.

In a subjective analysis of off-axis performance, it was clear that the combination of a wide anglular response from the Crystal LED B-series display maintained more consistent color performance than the comparative LED product. This capability is enabled by the size of the LED diodes and the way they are mounted to the display substrate. Current industry SMD-based design creates areas in which the individual diodes interact with each other and their mounting "package," affecting how light emanates from the display. Sony's LED technology enables light to uniformly emanate from the display, in what approaches a "lambertian" or perfectly uniform pattern of light.





4. Further Testing



Additional tests were performed during our analysis that provided either inconclusive or inconsistent results. What follows is a review of the methodologies behind these tests, with more specific results to be provided as part of future research plans.

Scanline Artifacts

As with nearly every type of modern display, LED systems use a scanning technique to illuminate pixels in a sequential order, rather than at the same time. The scanning frequency and sequence pattern may combine with the camera shutter to introduce unwanted and annoying artifacts, such as scanning bars or lines. In many LED displays, the ability to synchronize this refresh rate to an external signal generator is a requirement for camera-integrated systems. Additionally, many LED controllers that support virtual production workflows allow for the fine-tuning of the display refresh to the camera shutter, a feature which is included in Sony's ZRCT controller.

In our testing we found that many variables impacted the presence of scanline artifacts, which was further compounded by the fact that in some instances the artifacts were difficult to identify using on-set monitoring. Conditions such as camera position and angle, movement, movement speed, shutter speed and angle, display refresh and multiplex rate, and render platform settings all had an impact on the presence of these artifacts. Further evaluation is needed to determine system configurations that can consistently prevent this occurrence.

Color Reproduction Precision

For on-set virtual production, maintaining creative intent relies on the faithful reproduction of color throughout the rendering pipeline of the virtual background all the way to the display. The LED wall itself must include LED pixels capable of emitting red, green and blue light at wavelengths appropriate for reproduction of the full color space, and a high degree of consistency (also called uniformity) across the image. A lack of color precision may become very visible on-camera, whether it be a difference between adjacent pixels or different cabinets. In some cases, ambient temperature will cause color shifts (causing pixels mounted near the studio floor to appear different than those near the ceiling).

The wide-gamut color reproduction and consistency of the LED display will help in supporting the camera color sensitivity, and thereby enable more latitude for the Director of Photography to create evoke the specific "look" desired for a scene.

The LED displays intended for other applications, such as concert touring, conference rooms, and signage will often not be designed with the necessary precision necessary for an onset virtual production environment. The Sony Crystal LED system leverages a combination of component selection, calibration, and image processing to ensure a high degree of color reproduction precision, to the extent that content creators have found the display meets their standards for highly sensitive content review rooms, such as those found in post-production facilities.

While display color performance can be judged using establish standards and measured objectively, it was found that the addition of other variables such as camera color performance, practical lighting, and creative intent has created a new basis with which on-set display performance must be evaluated and that subjective measures factor more greatly in these environments than in critical review. It is for this reasons that further study is required to gather and share useful results, specifically the ability for the display to match camera performance and creative intent to a satisfactory level.

5. Workflow Guidelines

The combination of using a fine-pitch LED display volume with a high-resolution high-latitude camera opens new creative possibilities for content creation.

For the DP, this cohesive environment will provide more creative latitude in dynamic range and color management. For the art director and set designer, objects with more texture detail could be used. Lighting designers can leverage the crisp, wide-gamut emissive display to add practical illumination to the stage. And producers will appreciate the faster turn-around between scenes.

No two productions are alike so it is impossible to generalize about the "best" workflow appropriate for virtual production however what follows are our recommended considerations when developing production workflows:

Planning and Blocking

The display size and pixel pitch of the LED volume should be selected according to the required camera position (shooting distance) and lens focal length. In general shooting closer to the wall requires a finer pixel pitch to avoid visible artifacts.

In positioning the camera in relation to the LED display, consideration should be given to off-axis color shifts which might be inherent in the LED wall. A display that doesn't exhibit brightness or color shift when viewed from different angles will provide more flexibility in camera blocking, and dolly and crane moves and allow for more of the stage area to be utilized.

Staging should also consider camera positions that avoid Moiré artifacts. This may include positioning on-set objects far enough from the LED wall so that the LED pixels are sufficiently de-focused to avoid the Moiré interference pattern. If this isn't possible, you should choose an LED display with finer pixel pitch to avoid Moiré problems when the background is in-focus. Cameras with different OLPF optics may also reduce Moiré.

Proper alignment and calibration of the LED display is always critical. Special care should be taken in physical alignment to avoid visible cabinet seams or gaps, color accuracy and uniformity, luminance levels and grey-scale accuracy.

Stage lighting design should be mindful of avoiding direct reflections from the luminaires off the LED display surface, where specular reflections might be visible on camera. LED displays with the lowest possible ambient light reflectivity should be utilized.

Environment Creation and Rendering

To take full advantage of the capabilities of a high-resolution camera and display, Virtual Art Departments (VADs) should seek to utilize the highest-quality assets available. In some instances, this may require capturing 2D plates with high-resolution cameras, in others similar high-performance cameras and sensors can be utilized to scan real-world objects and import the photo-realistic imagery as 3D objects directly into a virtual environment.

Establish an imaging pipeline from the rendering engine to the display that maintains high enough bit-depth to avoid banding or black crushing artifacts. Be mindful of conversion between signal formats, or from copper to fiber connections, which can create unanticipated signal degradation or quantization.

Temporal artifacts – that is, those created by timing errors between the LED refresh rates and the camera shutter – can be avoided through properly synchronized image processing, or by using LED displays with the latitude to avoid scanning issues. Certain LED controllers like the Sony ZRCT-300 feature the ability to finely adjust the LED refresh rate to mitigate scanline artifacts created by the camera shutter and LED refresh interaction.

6. Conclusions

Technology Approach

Most commercially available LED displays use almost the same, or a very similar set of third-party components and design configurations. These include utilizing mini-LED size chips arranged in surface mount device (SMD) enclosures, positioning of 2.5mm to 4mm pixel pitch, off-the-shelf driver circuits and image processing chips and printed-circuit board (PCB)'s with epoxy encapsulation to reduce surface reflectivity.

While conducting our on-set testing of virtual production, it was apparent that there are several design attributes of the Sony Crystal LED display which provided uncommon and useful benefits for virtual production applications. For example, the Crystal LED uses a unique configuration combining finer pixel pitch (1.26mm) and the use of significantly smaller LED emitters to achieve a low fill-factor, with the vast majority of the display surface remaining black. The clear benefits were a reduction in visible Moiré patterns and elimination of visible off-axis color and luminance shift.

Second, a unique and proprietary image processing and scanning configuration enabled improved low-grey level performance and reduction in time-related scanning artifacts.

Third, the unique construction of the LED pixel modules anti-reflective surface treatment provided excellent brightness and uniformity consistency when viewed off-axis, and minimal ambient light reflections off the screen surface.

In Summary

Virtual production, and specifically in-camera visual effects, demands a new and unique set of performance requirements in both LED displays and cinema cameras. Most of these technical attributes are well understood -- including pixel uniformity, luminance, black level performance, off-axis color shift, and scanning artifacts. What has not been explored is the specific impact of these specifications for virtual production.

Through a series of practical tests using both objective and subjective measures, we learned which aspects of the LED performance are most important, and where they will benefit in preserving creative intent. The fine-pitch LED and minimal fill-factor configuration of the Sony Crystal LED revealed significant advantages during our tests. The ability to achieve a wider depth of field, position subjects closer to the display without Moiré artifacts, and photograph the background scene from oblique angles will provide more creative flexibility. The sensor configuration of the Original VENICE camera proved an excellent complement to the Sony Crystal LED display.

In conclusion, we feel that these cinematic tools will provide significant benefits in future virtual production workflows.

Special Thanks:

We would like to thank the following organizations and individuals that have dedicated their time to supporting our testing efforts:

- Epic Games