



Cameras and LED Walls — A Challenging Relationship

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Abstract

LED walls have become an important part of scene design in many media and entertainment applications, but LED walls are also being used more and more for virtual backgrounds and similar applications.

However, there are several challenges in combination with cameras that often make it difficult to achieve an optimal result. A fundamental problem is that both the LED walls and the image sensors in the cameras use discrete pixel structures, which in certain cases can lead to interference between those two structures, so depending on the application, certain camera positions and image settings must be avoided, which in turn can lead

to unwanted limitations in the image composition. There are limited ways to minimize this potential interference with a given LED wall, but on the camera side there are some ways to get the best possible result through optimized optical pre-filtering. However, the extent of the problem depends heavily on the camera technology used. Cameras that have the same resolution for all three colors offer significantly more possibilities to enable the best possible optical pre-filtering for the circumstances.

In addition, new applications, especially in VR and AR, where the LED wall is operated at an increased frame rate, pose completely new

challenges for image capture technology. For these challenges, it is of crucial importance that the image sensors in the camera have a global shutter, because this is the only way to expose and read out all image elements simultaneously in a short-time exposure. Additionally, there are possibilities, especially on the camera side, to create a smoother and easier integration of cameras into the production environment. For example, through new functionalities such as the implementation of a delay circuit between the image sensors and signal processing for shifting the exposure moment.

Introduction

In scene design of television productions, screens of various types have been used for many years. Where initially cathode ray tubes were used, these have been replaced by plasma and LCD screens or LCD-based projections.

There were also challenges for camera technology when using CRT screens, particularly the synchronicity of the monitor signals and the cameras. Artifacts often occurred, especially when multiple monitors with unsynchronized sources or monitors with a different frame rate than the cameras had to be captured. Some plasma monitors used a frame rate independent of the signal source, resulting in very similar interference patterns to CRT monitors with frame rates different from the camera. When capturing LCD-based monitors, there were rather fewer problems overall due to artifacts in the image reproduction.



Figure 1 – Camera in front of a LED wall during an EBU workshop at Leyard Europe.

However, today LED screens (Fig. 1) are used almost exclusively when a virtual background is needed in a scene. This creates several

challenges in combination with cameras that often make it difficult to achieve an optimal result.

LED Walls

A fundamental problem is that both the LED walls (Fig. 2) and the image sensors in the cameras (Fig. 3) use discrete pixel structures, which in certain cases can lead to interference between the two structures, so that depending on the application, certain camera positions and image settings must be avoided, which in turn can lead to unwanted limitations in the image composition.

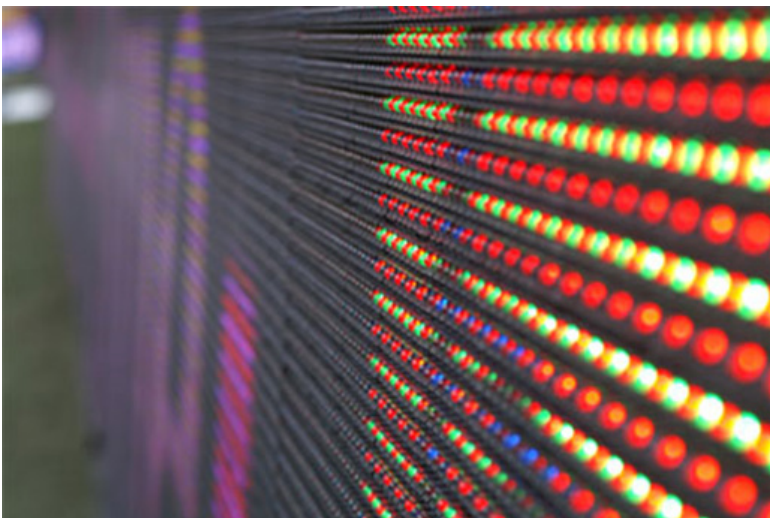


Figure 2 – Close up of a LED wall.

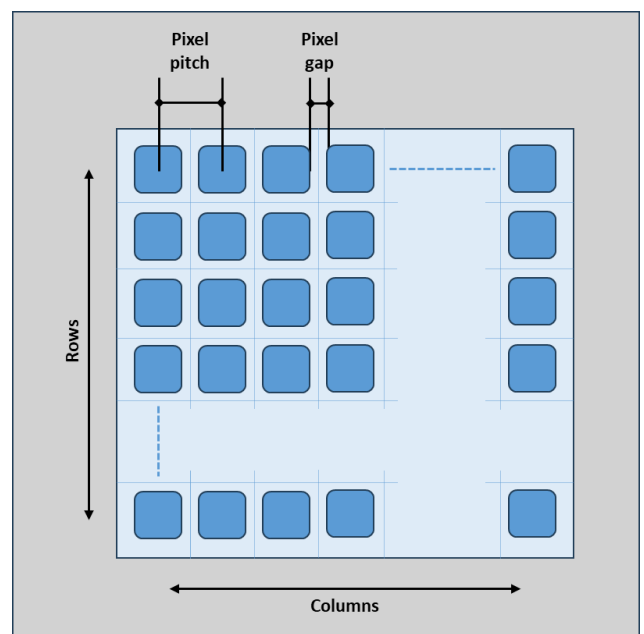


Figure 3 – Pixel structure of a camera imager.

There is a large selection of LED walls for a wide variety of requirements and there should be one or more versions for most applications that enable an optimal picture result.

In principle, LED walls with a smaller pixel pitch are always to be preferred, but the fill factor (Fig. 4) must also be taken into account, with a larger one always delivering better results.

However, a smaller pixel pitch with the same wall size also means higher resolution, which in turn requires more effort from the image processors. It is therefore not always possible to choose an LED wall that is free of all restrictions, due to the availability of the required size, or much more trivially, due to the costs.

With any given LED wall, there are limited ways to minimize this potential interference. On the camera side, however, there are a few ways to achieve the best

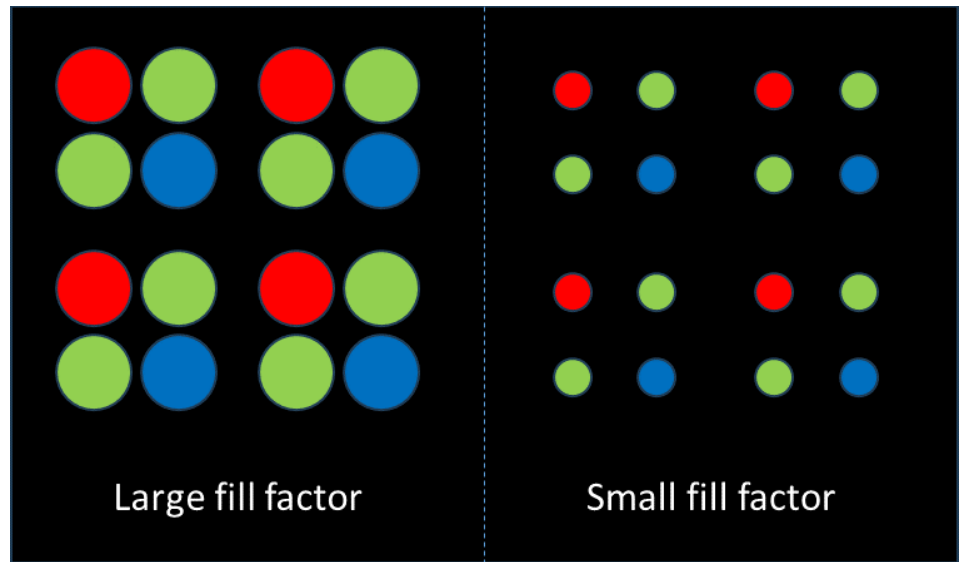


Figure 4 – Comparing fill factor at LED walls.

possible result through optimized optical pre-filtering. The extent of the interference problem depends heavily on the camera technology used. Cameras that have the same resolution for all three colors offer

significantly more options for enabling the best possible optical pre-filtering for the respective circumstances than is possible with cameras with a single image sensor with a color filter array.

Camera Imagers

Only CMOS image sensors are used in professional cameras today. Earlier versions often had a rolling shutter, but most current sensors have a global shutter. With global shutter operation, all pixels are always read out and reset simultaneously in all operating modes, whereas with rolling shutter operation, each pixel has a different exposure moment in time.

In most applications, also when capturing LED walls, there is no big difference between the two shutter

versions. However, it should be noted that there are certain applications that only work with a global shutter. These are, for example, all applications in which the LED wall is operated with an increased frame rate and a short-term exposure is used on the camera in order to take a picture of the LED wall at a specific point in time.

On the one hand, the increasing number of pixels in the camera sensors due to the new video formats lead to an increase in

image resolution, but there are also increasing situations in which the pixel structures of the camera sensors and the LED walls interfere with each other. However, there are a few points to consider that have an impact on the problems to be expected. This includes targeted measures on the camera side to minimize interference, but also things that have an impact on the image quality that result from physical conditions.

Resolution/Sharpness

In a camera system, several parameters influence image sharpness [1], including the number of pixels, the MTF performance of the lens, but also the optical low-pass filtering (Fig. 5).

Since the number of pixels is determined by the video format, and the MTF performance of the lens has practical limits, the only thing that can be influenced in camera development is optical low-pass filtering.

According to the Nyquist theorem, no signal must be present for interference-free sampling above half the sampling frequency, which means that optimal optical low-pass filtering should cut off the image signal with a steep edge just below half the sampling frequency.

However, such an optical brick-wall filter (green dotted line in Fig. 6) does not exist and the compromise used instead is an optical low-pass filter that has a cosine response with a gentle roll-off with a notch at the sampling frequency (blue dotted line in Fig 6). This filtering offers a good compromise between the sharpness of the image and the aliasing behavior of the camera.

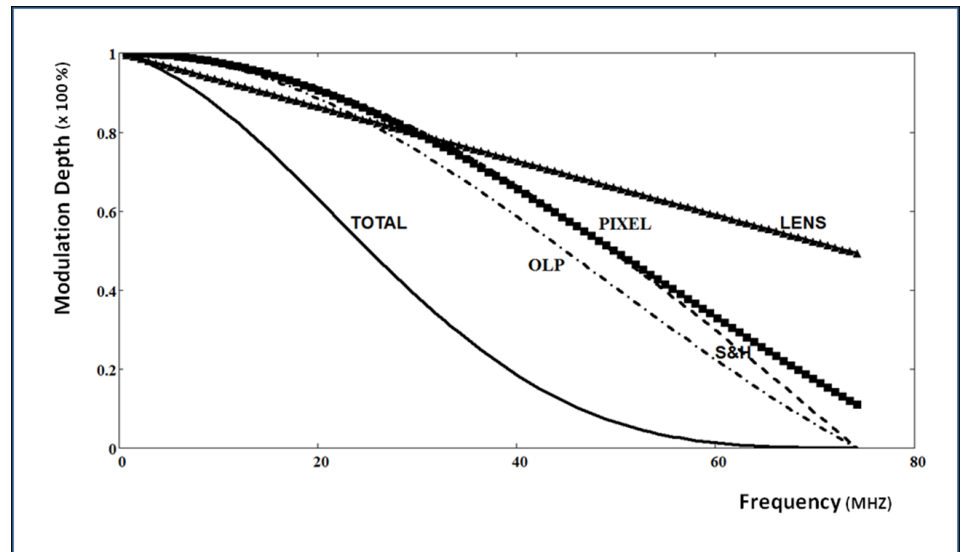


Figure 5 – Parameters influencing image sharpness.

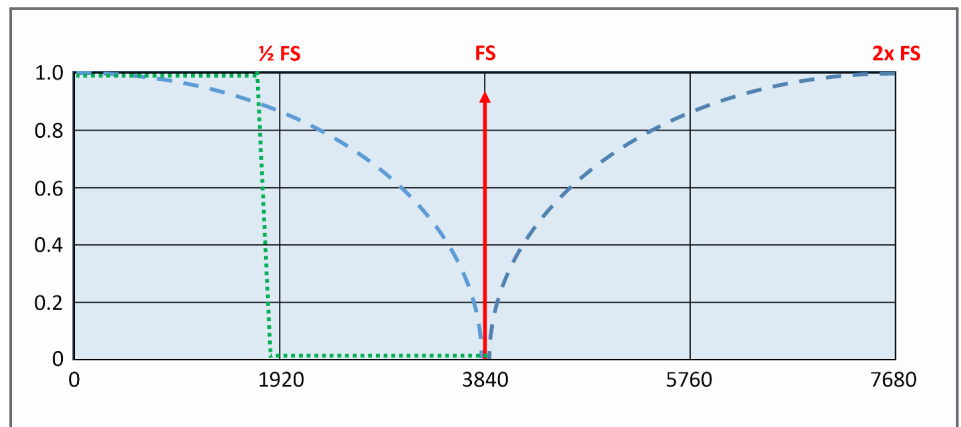


Figure 6 – Optical low pass filtering in a UHD imager.

Optimized Filtering for Alias-critical Situations

As already mentioned, the superimposition of the pixel structures of the LED walls and the camera sensors can lead to interference, which is noticeable through aliasing in the image. These disturbances, which are low-frequency folding frequencies, cannot subsequently be filtered out. Therefore, these disturbances can only be prevented from occurring. For this purpose, additional optical low-pass filters can be used in the camera, which typically have a notch

at half the sampling frequency. This significantly reduces aliasing, but the resolution of the image suffers as a result.

However, since the perceived image sharpness does not depend so much on the reproduction of the highest frequencies, but rather on the modulation depth of the middle frequencies, for example the frequency where MTF is 50% of the maximum value as well as the area under the MTF curve [2], which does

not change too much due to the additional filtering, the losses are acceptable for most applications.

However, the loss of resolution is the reason why this additional optical low-pass filtering is not used as standard, but only as an option when required. In addition, filters with single or double dip characteristics can be used, whereby the relationship between alias reduction and loss of sharpness changes in one direction or the other.

Figure 7 shows the characteristics of the various optional optical low-pass filters, but the reduction in the modulation transfer function can also be clearly seen there.

Figure 8 shows the total modulation transfer function resulting from a camera system – it can clearly be seen that the losses are visibly lower than one would expect looking at the filters alone.

Single Versus 3-imager

Most broadcast cameras use three image sensors, with a prism color splitter splitting the scene light into the three colors (Fig.9). These color separations are then captured by three identical full-bandwidth image sensors. The scanning frequency is therefore identical for all three colors and the optimal optical pre-filtering that has to take place in front of the sensors is identical for all colors.

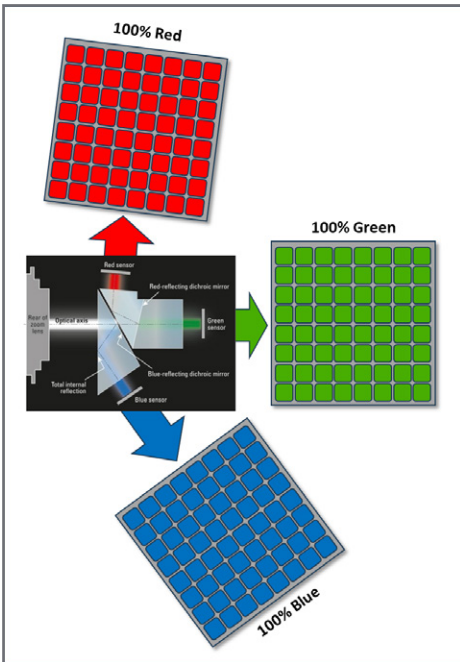


Figure 9 – Color separation in a typical 3-imager broadcast camera.

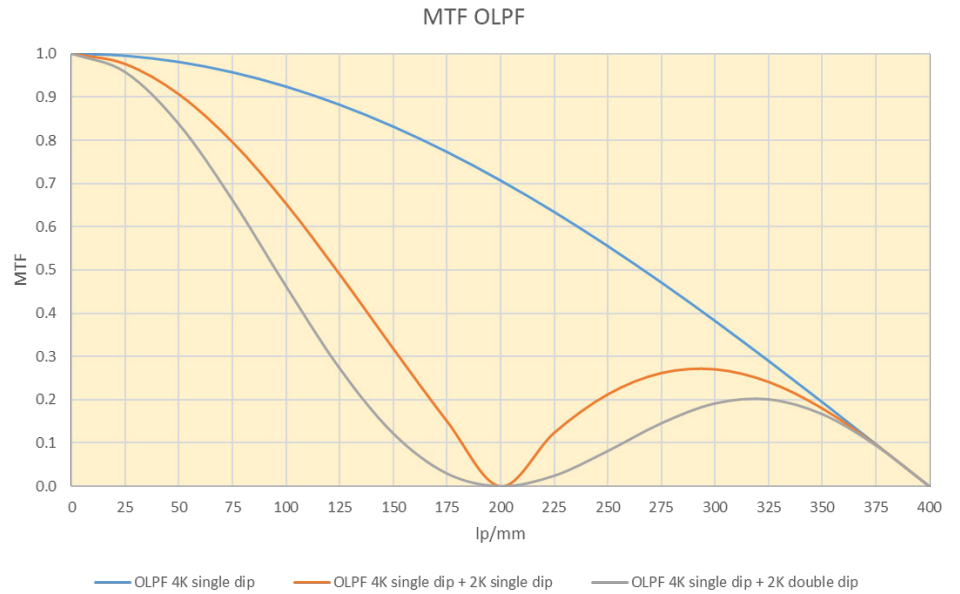


Figure 7 – Comparing MTF of the different optical low pass filters.

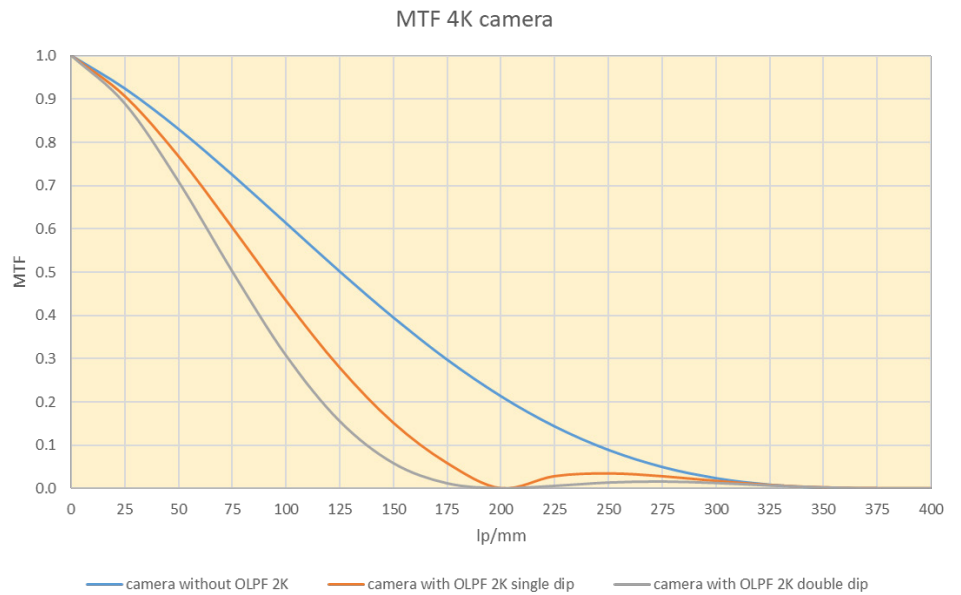


Figure 8 – Comparing the overall MTF of a camera system with different optical low pass filters.

This is different in a single-imager camera with a color mosaic filter applied to the sensor, usually based on the Bayer pattern principle, in which every second pixel has a green filter and every fourth pixel has either a blue filter or a red filter (Fig. 10).

As a result, the different colors have a different sampling frequency and optimal optical low-pass filtering for all colors at the same time is therefore not possible.

In practice, the green signal is optimally filtered and the other two colors have poorer filtering, which is also clearly reflected in the corresponding disturbances in the image (Fig. 11).

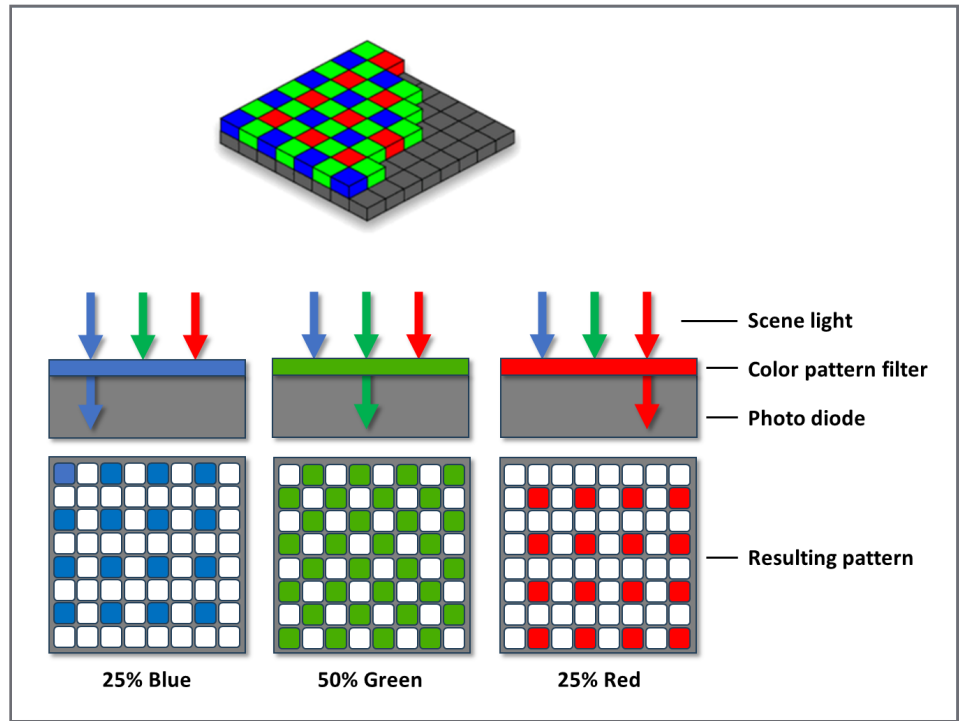


Figure 10 – Bayer pattern filter at a single imager camera.

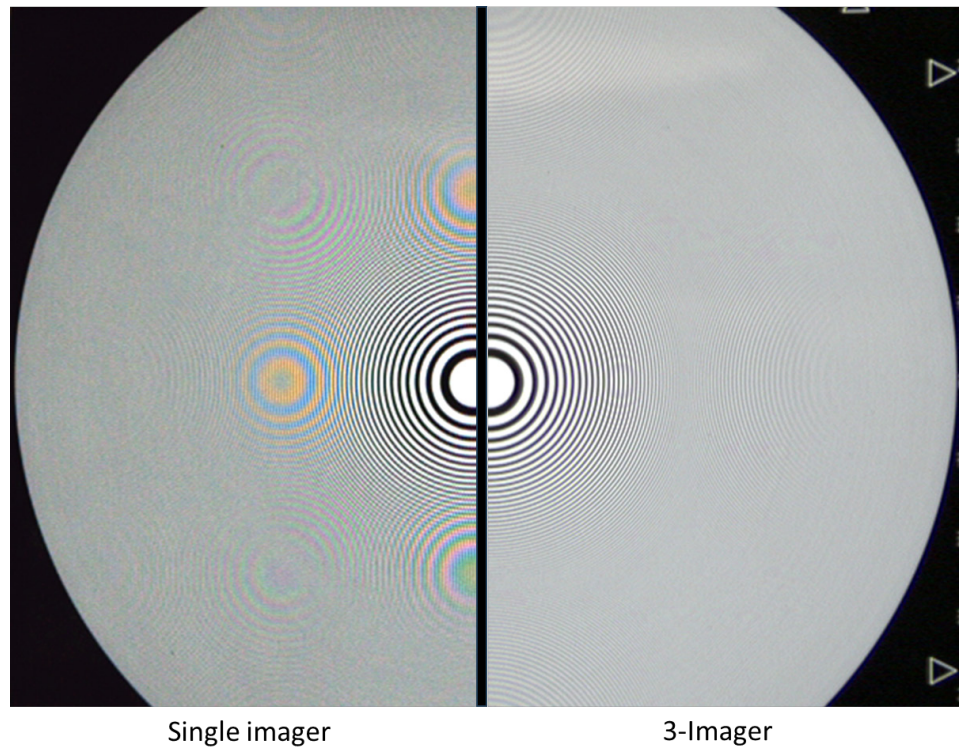


Figure 11 – Comparing alias between single imager and 3-imager cameras.

New Applications

VR/AR

In the VR and AR areas in particular, there are applications in which the LED wall is operated with an increased frame rate, which poses completely new challenges for the camera technology. The camera is operated with a short-time exposure, which is coordinated with the exposure time of a single image reproduced by the LED wall.

For these applications, it is of crucial importance that the image sensors in the camera have a global shutter, because this is the only way that all image elements can be exposed and read out simultaneously in a short exposure time. In addition, there are possibilities, especially on the camera side, to create a smoother and easier integration of cameras into the production environment. This requires a solution that allows the exposure timing to be continuously shifted.

Electronic shutter

An electronic shutter is used to reduce the exposure time of a camera. The electronic shutter at a certain point in time erases the charge accumulated in the photodiodes, thereby starting a new exposure. And only the amount of charge that is accumulated between the moment of extinction and the moment of readout is then used (Fig. 12).

How to select the image

However, the moment of the exposure cannot be freely selected in comparison to studio timing, but it is always the period immediately before the read-out time of the camera sensor.

Of course, the synchronization signal for the camera can be shifted so far that the exposure moment takes place exactly when it is needed. That would mean, however, that a different synchronization signal would be required for each camera that required a different exposure

moment. And what's more, the output signal from the camera is then no longer in sync with the studio timing and it would then have to be delayed again until it is in sync with the rest of the signals.

If, however, a circuit is integrated in each camera that makes it possible to set a freely selectable delay of up to one frame between the sensor output and the signal processing as shown in the circuit called V-shift in Figure 13, the exposure moment for each camera can be freely selected without any problems.

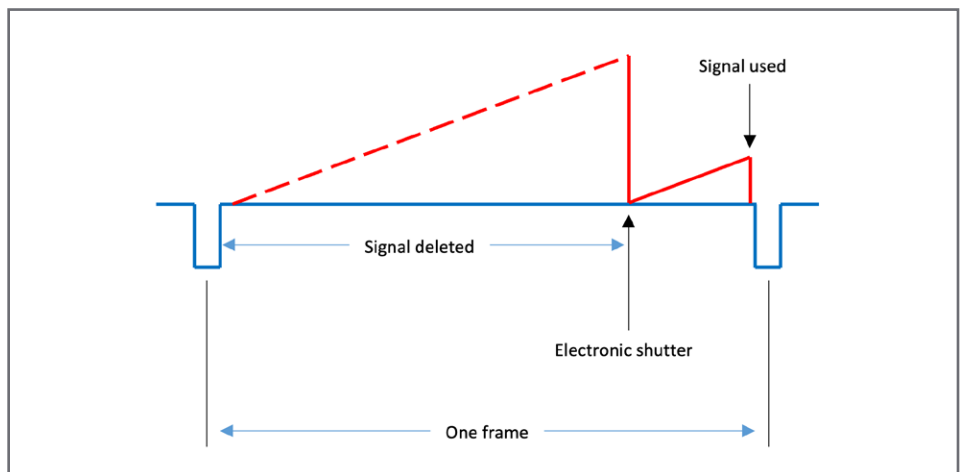


Figure 12 – Electronic shutter used to reduce exposure time.

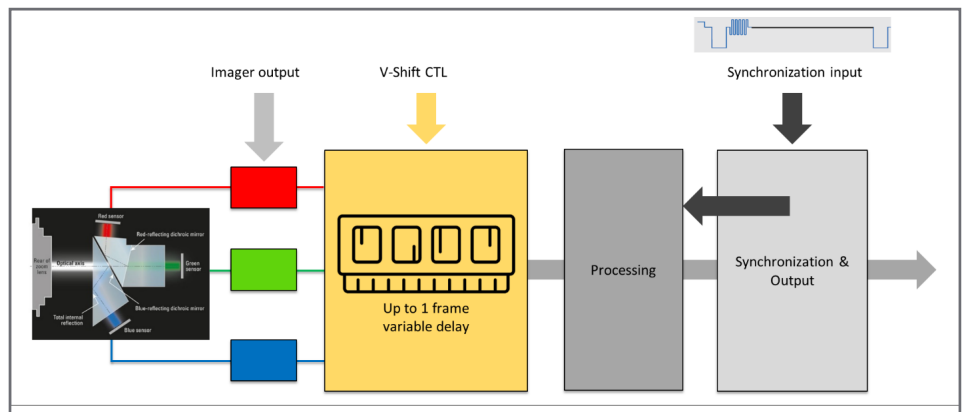


Figure 13 – V-shift variable delay circuit between imager output and signal processing.

Figure 14 shows an example of a situation where the LED wall is operated with four times the image frequency and the camera is only supposed to take the third image.

To do this, the electronic shutter is set to less than or equal to 1/200 seconds (at 50 Hz) or to 1/240 seconds (at 59.94 Hz) and then the V-shift setting is changed until the exposure moment of the camera sensors is exactly synchronous with the desired one image on the LED wall.

Compared to changing the camera synchronization signals, this solution is much easier to use and also much more flexible and time-saving.

How to capture multiple images

In addition to the requirement to capture only a single image of an LED wall operated with a higher frame rate, there are also applications where all images are required. To do this, the camera must then be operated at the same frame rate as the LED wall and, in addition, the exposure moment must still be shifted. To reduce crosstalk between two images, it can help to reduce the exposure time slightly with the help of the electronic shutter.

The sensitivity of the camera sensors decreases in direct proportion to the exposure time, and due to the significantly shortened exposure time in these applications, the requirements for the light sensitivity of the image sensors are very high.

Even more problematic, however, is the solution often used with UHD cameras in high-speed operation to read out only a small portion of the UHD pixels. In this case, only every second pixel in the horizontal plane and every second line is read out (Fig. 15). Of the 3840x2160 pixels of the UHD sensors, 1920x1080 or Full HD are read out, but this leads to large light-insensitive areas between the pixels read out, which in turn does not lead to acceptable results in applications with LED walls, especially due to alias interference.

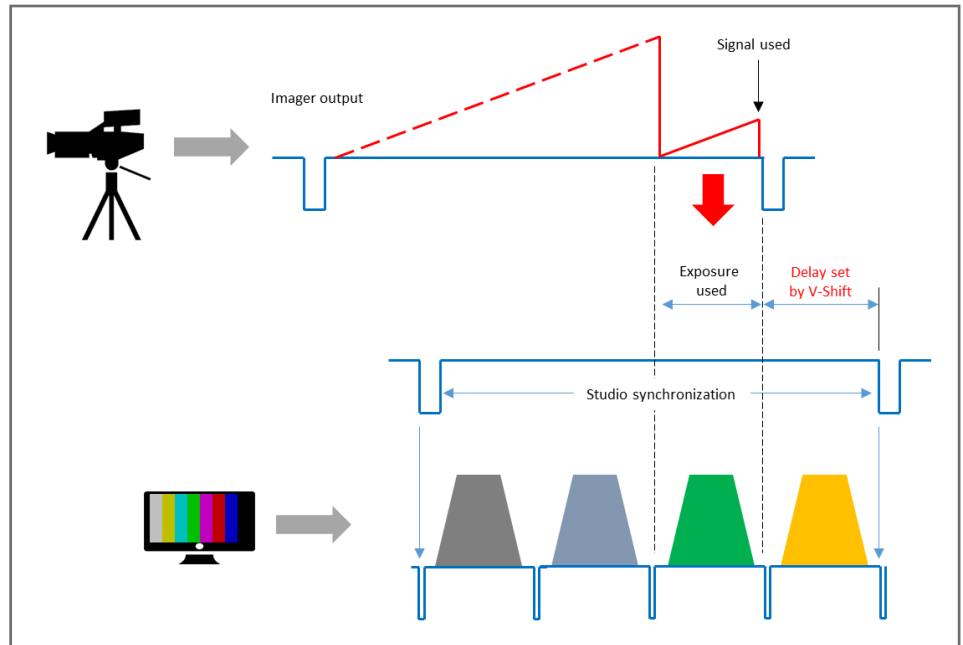


Figure 14 – Electronic shutter and V-shift function to select a single image.

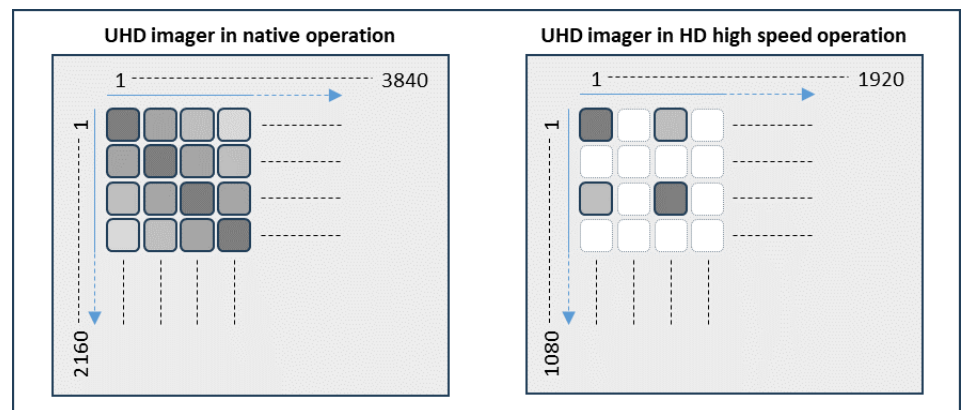


Figure 15 – Comparing UHD imagers in native operation and HD high speed operation.

However, the possibility of reading out all active picture elements of the image sensors in the required frame repetition rate, such as 3x(150/180) or 6x(300/360) frames, will offer the best possible solution. Even with these solutions, only cameras with three image sensors will deliver the best possible results.

The latest generation of 2/3" UHD CMOS sensors already allow operation with up to 6 times the frame rate, even in connection with global shutter [4/5].

However, the challenges for the image sensors and the subsequent signal processing are very high, the

bandwidth requirement increases to the same extent as the refresh rate (i.e., at 6 times the speed), a 6 times larger bandwidth is required, with three 16-bit UHD sensors there are then signals with over 300 Gbps to process.

$$3 \times (4224 \times 2248 \text{ pixel}) \times 16 \text{ bit} \times 359.64 \text{ frames} \times 2\text{-times sampling (for CDS)} = 327.84 \text{ Gbps}$$

A conversion of native UHD signals from the sensors into 1080p signals for signal processing offers optimal image quality in 6x 1080p through oversampling by the sensors and thus represents an optimal compromise for many applications.

Conclusion

As the title of the paper indicate: "Cameras and LED walls – A challenging relationship," the use of cameras together with LED walls brings with it some special challenges. But as is so often the case, there are solutions to achieve a best possible result despite the challenges.

This starts with additional optical low-pass filters in the camera that are optimized for LED applications, continues with additional delay circuits in the camera signal processing for freely determining the exposure time, through to high-speed cameras with three 2/3" image sensors that can be operated

natively with UHD pixel scanning in the required frame rate.

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Nederland

Reference

- [1] K. Weber, Dr. Ir. P. Centen “4K, HDR and Further Image Enhancements for Live Image Acquisition” presented at the SMPTE 2015 Annual Technical Conference & Exhibition, Hollywood, CA, Oct. 2015
- [2] Imatest, Documentation – v23.1 “Sharpness: What is it and How it is Measured”, www.imatest.com/support/docs/32-1/sharpness/
- [3] Dr. Ir. P. Centen “Pixel size and the effect on performance in 2K, 4K, 8K acquisition” presented at the SMPTE 2017 Conference & Exhibition, Sydney, Australia, Jul. 2017
- [4] K. Weber, J. Rotte “New Generation 2/3”, 9.5 Mpix CMOS Imager Combines Charge-domain Global Shutter Operation with Exceptional High-speed Capability” presented at the SMPTE 2021 Annual Technical Conference & Exhibition, Virtual, Nov. 2021
- [5] K. Weber, J. Rotte, “A 2/3-in. 9.5-Mpixel CMOS Imager With High Frame Rate and HDR Capabilities” SMPTE Mot. Imag. J., Volume: 130 (Issue: 5), June 2021.

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