

White Paper

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Quantifying Flicker in an Ephesus LED Luminaire

Abstract: Most luminaires have some inherent flicker as a result of the way the lighting element receives power. Whether or not flicker becomes a negative issue is dependent on if it can be perceived, either by the human eye or on a camera. Especially in environments such as sporting venues, where cameras capture action at very high frame rates for slow motion replay, flicker inherent in the lighting can be a significant problem. This paper examines how flicker can be measured and classifies the acceptability of the Ephesus Arena fixture.

Introduction

Flicker is an unsteadiness or pulsing effect in light, which can cause strobe-like effects where motion appears slower or disjointed. It can be defined as rapid fluctuation of light output in a cyclical manner¹. Flicker in filming results from frames containing little or no light, making the image seem to sputter or blink. Conventional lighting systems can produce flicker as a result of the light source being powered from a standard 50 or 60 Hz alternating current (AC) power line. For LED lighting, power is converted to a direct current (DC) supply and in general they are not prone to flicker at full power. However, many LED luminaires are susceptible to flicker when dimmed, depending on how dimming is accomplished.

Although nearly all luminaires have some flicker, much of it is at a high enough frequency to be imperceptible. To understand if flicker in a given fixture is acceptable requires a detailed look at the two types of “sensors” capable of perceiving it – the human eye, and the HD camera.

Human Perception of Flicker

The human eye cannot directly detect flicker at frequencies higher than 100 Hz, however, indirect detection through perception of strobe-like effects has been reported at 500 Hz¹.

¹ Alliance for Solid-State Illumination Systems and Technologies (ASSIST). 2012 *ASSIST recommends ... Flicker Parameters for Reducing Stroboscopic Effects from Solid-state Lighting Systems*. Vol 11, Issue 1. Troy, NY Lighting Research Center
<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp>

Detection of flicker can be quantified using two properties of the light: the percent flicker and the frequency. For a given light source, these properties can be measured on an oscilloscope using a photodetector.

The percent flicker is the difference between the minimum and maximum light output during a waveform cycle. The ASSIST paper¹ gives the formula to calculate it as:

$$\text{Percent Flicker } (p) = \frac{\text{Maximum} - \text{Minimum}}{\text{Maximum} + \text{Minimum}} \times 100 \%$$

Regardless of frequency, if a light output ever reaches zero, the light is said to have 100% flicker. Common flicker factors are shown in the table below². Ephesus is currently performing testing on their Arena series of lights to capture this light output curve. For the sake of completing the calculation, we will assume flicker is worst case, 100%. This will be updated once the current testing is complete.

lamp type	flicker factor
LED dimmed at 50%:	99 %
HMI magnetic ballast:	40 - 70 %
Street lights magnetic ballast:	50 - 70 %
Fluorescent magnetic ballast:	30 - 60 %
Fluorescent electronic ballast:	0 - 12 %
Household bulbs:	10 - 15 %
Tungsten lights	0 - 10 %
HMI electronic ballast:	1 - 3 %
Sunlight:	0 %

The second component in estimating the likelihood of flicker detection is frequency. The Ephesus Arena fixture uses a pulse-width modulation dimming strategy, which dims the lights at a frequency between 20,000 and 40,000 Hz. In developing this method, the Lighting Research Center (the world's leading university-based research and education organization devoted to lighting) only tested up to frequencies of 10,000 Hz because flicker is generally negligible at frequencies higher than that. Percent likelihood of detection is given by:

$$\text{Likelihood of detection } (d) = \frac{25p + 140}{f + 25p + 140} \times 100\%$$

Where *p* is percent flicker and *f* is frequency. For the Ephesus light this is given as:

$$d = \frac{25(100) + 140}{20,000 + 25(100) + 140} \times 100\% = 11.6\%$$

² http://www.davidsatz.com/aboutflicker_en.html

This falls in the lowest bin for likelihood of detection. Further, the ASSIST paper defines a five point scale for flicker acceptability, where +2 is very acceptable, 0 is neutral and -2 is very unacceptable. Even assuming worst case of 100% flicker, the Ephesus Arena light scores a 1.96, which is very acceptable. **Given the very high modulation frequency, human perception of flicker is not a concern for the Ephesus Arena light.**

Camera Perception of Flicker

Unlike human perception of flicker, there are no well-defined metrics for determining whether or not a camera will pick up flicker. The severity depends on many variables, including the camera frame rate and shutter angle, the light source and the supply voltage. Much of the flickering observed with standard cameras is a result of the camera frame rate being out of sync with lights cycling at 50 or 60 Hz from AC power. For this reason conventional discharge lighting such as metal-halide and fluorescent lights with older magnetic ballasts are particularly susceptible to flicker. Use of electronic ballasts largely mitigates this issue for discharge lighting.

For LED's the primary concern with flicker is when they are dimmed by pulse modulation. In theory, if the frequency of light modulation is significantly higher than the frame rate the camera is capturing, with a moderate exposure time, the image should not flicker. The Ephesus Arena lights modulate at 20,000 Hz (worst-case). **Therefore, even at a high frame rate of 2000 fps there are at least 10 pulses of light within a single frame, which is more than sufficient to avoid flicker.** A sample plot of this is shown below, where the green cycle is the camera frame rate and the blue cycle is the LED source. Additionally, light modulation is staggered within the LED array itself and across a system of lights within a venue, so it's very unlikely a camera would detect any flicker in an Ephesus Arena light.

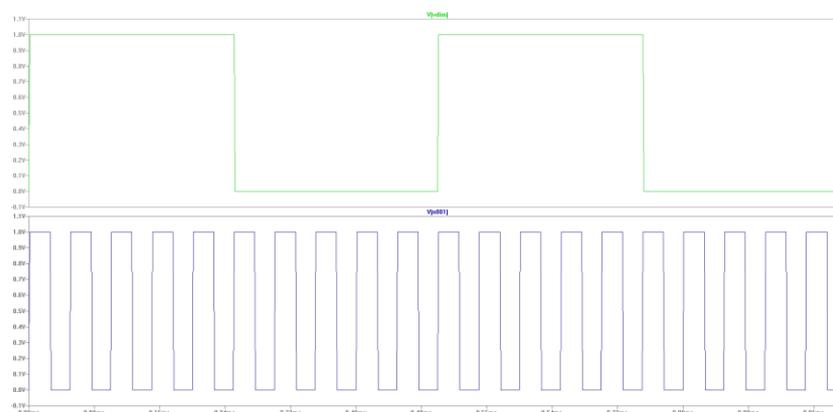


Figure 1: Sampling Rate of Camera vs. LED modulation

High level slow-motion cameras have the ability to film between 2,000 and 4,000 fps with very short exposure times. For capturing rates this high, the overall light

requirements are also very high so it's unlikely the lighting system would be dimmed at all. If the system is not dimmed, the constant DC source in the Ephesus luminaire supplies light that is completely flicker-free.

Ephesus has done some testing of this theory in the Syracuse War Memorial hockey arena using television quality cameras that filmed in high definition 1080i at 59.94 fps (SMPTE 294M standard). No flicker was visible in the system.

Conclusion

Based on this analysis, it is virtually impossible to perceive flicker in the Ephesus Arena fixtures with the human eye, and it is very unlikely even high frame-rate cameras for slow motion will detect flicker. Ephesus will continue to test its fixtures and will update this information as further data is available.