BY MIKE WOOD

Flicker

I'VE TALKED ABOUT ROLLING SHUTTER EFFECTS in this column before (*Protocol* Summer 2011). If you recall, this is the particular problem that CMOS-based camera sensors (now almost ubiquitous) have with the pulsing, PWM, light output from most LED luminaires. It produces bands or stripes of light and dark on video or static digital imagery. This a problem that isn't going away, and even the most recent cameras and luminaires exhibit the problem. For example, **Figure 1** shows a photograph I took of the output from an LED luminaire recently.

The photo was taken with an iPhone. Cell phone cameras are particularly good (or bad, depending on how you look at it) at showing this problem as the CMOS sensor is scanned at a fairly low rate that exacerbates the problem. Nothing of the colored banding was visible to the eye, it's all in the camera sensor. The problem is always worse when lights are dimmed down, and often worse when mixing multiple colors as I was here.

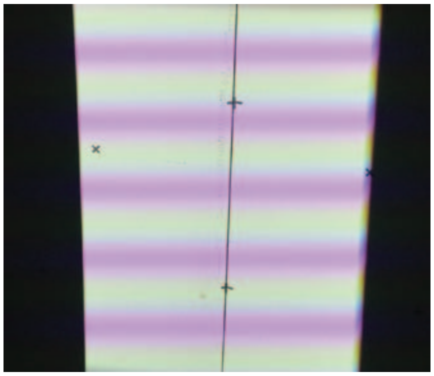

Figure 1 – Rolling shutter effect

However, this isn't what I want to talk about today! So why mention it? Well, I had tacitly assumed that the only place we in entertainment lighting were seeing problems with flicker was with cameras and rolling shutters. I thought we were well up past the rates at which flicker could be a problem for the unaided human eye. I was wrong!

The problem of flicker, particularly from LED light sources, is a topic that you read more and more about in current lighting literature. A recent report from the Department of Energy and Pacific Northwest National Laboratory highlighted the problem and possible health issues, which have now been codified in *IEEE 1789-2015*. It's also a controversial topic, with many manufacturers of LED lighting saying that *IEEE 1789* goes too far and is way too conservative. There are deep vested interests at play here, as with many things, so it's hard to winkle out the truth. Either way, it's sensible to know what's going on with flicker and to understand the arguments so you can make your own decisions.

The concerns from light flicker range from the annoying through the unhealthy all the way up to life threatening if you happen to suffer from photosensitive epilepsy. Low frequency flicker is obvious: it's visible as lights flashing or from the stroboscopic effect flicker gives to moving objects. One instance of this I find particularly annoying is when the brake lights on a car are being dimmed using low speed PWM (**Figure 2**). As your eye moves across the light, you see a train of individual dots rather than a single light. Very distracting. You see this effect on LED indicators all the time;

PHOTO: ALLEN GRUBBS

Figure 2 – Strobing stop lights

I always notice it when lying in bed at night in hotel rooms on the LED lights on the smoke detector or the TV.

A similar effect happens with video projectors that use the internal spinning dichroic disc. If you scan your head rapidly from side to side (or just walk past the projection screen) as you view the image you end up seeing three images, one each in red, green, and blue, spatially offset as your head moves. Most video projectors now have doubled the speed of the disc to mitigate this issue, but I can still see it. Stroboscopic effects can be indirectly dangerous as they can make rotating machinery appear to be stationary. Health effects of long term exposure to flickering light in the workplace can be headaches, fatigue, eyestrain, and migraines.

The DoE report emphasizes the importance of understanding the difference between sensation and perception. It explains that sensation is the physiological detection of external conditions that can lead to a nervous system response, while perception is the process by which our brain interprets such sensory information. Some sensory information is not perceived, and some perceptions do not accurately reflect the external conditions. As a result, some people who suffer from flicker sensitivity may not be aware that flicker is the reason they are suffering, or even that the light source responsible for their suffering is flickering.

> "I thought we were well up past the rates at which flicker could be a problem for the unaided human eye. I was wrong!"

Exacerbating this is that we all differ in our response to flicker. Some individuals, such as children and migraine sufferers, may be very sensitive, while for many others flickering lights have no adverse effect. The vast majority of light sources flicker to some extent. This includes incandescent, HID, and fluorescent lamps as well as LEDs. Non-LED conventional sources tend to flicker at twice the frequency of the mains power signal driving them (120 Hz in North America, 100 Hz in Europe) and the effects from flicker are minimal. Those light sources that exhibited annoying flicker, in particular fluorescent lamps with magnetic ballasts, were improved by switching to electronic ballasts running at high frequencies. The flicker from fluorescents was particularly objectionable because it was a highly modulated flicker where the lamp intensity dipped significantly between peaks. The natural thermal inertia of incandescent lamps tends to smooth out those peaks and valleys, meaning that the flicker, although still present, is much more gentle in its amplitude. It's the move to solid state lighting and LEDs that has brought the topic to the forefront again. Now light sources flicker again, to a greater or lesser extent, particularly if dimmed using PWM, and it's become a concern.

Fundamentally our sensitivity and perception of flicker is affected by six main factors:

1. Frequency of the light modulation

Obvious flickering below 100 Hz, although annoying and a problem for epileptics, isn't that big a problem. We know it's flickering and avoid it. It's flickering from 100 to 200 Hz that is potentially the worst. It's imperceptible, in that we don't notice it's there, but it still has physiological effects.

2. Amplitude of the light modulation

Pretty obvious: The greater the range from high to low of the flicker, the worse the effect. A light that goes completely off, such as a theatrical strobe, is the worst.

3. Average illumination intensity

Bright light is worse than dim.

4. Wavelength of the light

Red light flicker has much more effect than blue. Deep red is worse, and a red-blue alternation can be particularly bad.

5. Position on the retina at which stimulation occurs

As with movement, we are very sensitive to flicker in our peripheral vision. However, the unperceived effect of flicker in the center of the retina is actually more damaging as it is transmitted to a greater area of the visual cortex. The more of the retina that is stimulated, the worse the effects. This means that perhaps unexpectedly, closing your eyes when looking at a strobe actually makes the situation worse, not better! Your eye lids diffuse the light across your whole retina. You need to put your hand over your eyes, not just close them.

6. Degree of light or dark adaptation

Flicker is more noticeable with a dark adapted eye at night but flicker at photopic (light adjusted) levels is more damaging.

The range of frequencies at which flicker is either noticeable as a sensation or perception is one of the areas of controversy. It seems that all agree that flicker is of no concern at frequencies above 1 kHz and of real concern below 200 Hz. However, there is a grey area, particularly between 200 Hz and 500 Hz, where opinions differ on how important flicker is. Some researchers say that the health effects above 160 Hz are negligible, while others maintain that much higher frequencies can be a problem.

> "... closing your eyes when looking at a strobe actually makes the situation worse ..."

The IEEE takes what some consider a fairly conservative approach in *IEEE 1789* and recommend that flicker frequencies, represented by PWM rate in LEDs, be kept high. The standard defines a metric for acceptable flicker as follows:

$$\text{Allowable Percentage Flicker} = 0.08 \times \text{Flicker Frequency}$$

To understand this, we have to know what "percentage flicker" means. The IESNA has previously defined this in *IES RP-16-10*. **Figure 3** shows a hypothetical light source with a periodic flicker in amplitude. We need to know the maximum value and the minimum value that the light amplitude reaches in each cycle.

Now we can define:

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

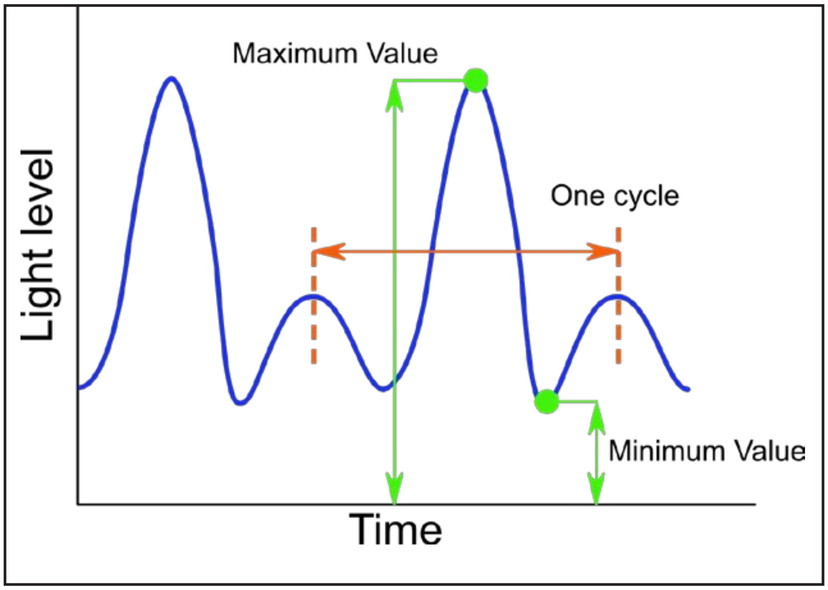

Figure 3 – Flicker percentage

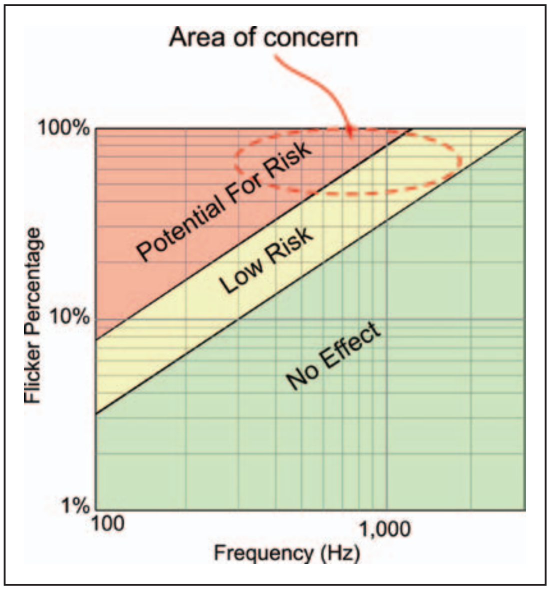

Figure 4 – *IEEE 1789* risk chart
Reference: Modified from *IEEE 1789-2015*

This will vary from 0%, no flicker, to 100% when the minimum amplitude goes all the way down to zero light output. This is an old metric which is of limited use on its own in that, although it measures amplitude changes, it tells us nothing about the waveform shape, the duty cycle, or the frequency. The new IEEE metric combines this with the frequency making it more useful.

Let's look at a couple of examples. For a 120 Hz flicker frequency (common for pre-LED light sources) the maximum allowable flicker is 0.08 x 120 which rounds up to 10%. That is, we are allowed 10% flicker percentage for that light. Similarly, for 1,250 Hz, 100% flicker is allowed. What this means is that anything above 1,250 Hz is of no concern and *IEEE 1789* only applies to frequencies lower than that.

Now you see why this is perhaps of relevance to us in entertainment lighting. 1,250 Hz is not that high as far as the PWM drivers in current luminaires go. Some products use PWM rates over this frequency, but many do not. A typical product may be running at 400 Hz, which means that the allowable flicker percentage would be about 32%. Because of our need for high quality dimming, and smooth color mixing, it's not unusual for the PWM signals to be almost a full magnitude square wave, and thus close to 100% flicker. **Figure 4** summarizes the situation recommended by *IEEE 1789*, and I've highlighted the area that I suspect many entertainment LED luminaires operate in when dimmed down.

I should emphasize that the potential risk areas are for sensitive individuals, not the entire population. However, we could all get headaches or eyestrain. One other very important point is that this data is for continuous exposure, for a full working day. A few minutes, or even an hour or so, in a theatrical event or concert likely won't be a problem. There's also no data that I can find about the effect of multiple lights, all flickering at 400 Hz, but all out of phase with each other so that the flickering tends to overlap. Does that mitigate the effect? Does it make it worse? I imagine the answer is, "well maybe; it depends." You could imagine that lights overlapping on a cyc tend to mitigate the effect but that two lights both shining at you from differing angles may heighten it. Who knows?

As I've mentioned, these figures aren't universally accepted. There's a significant faction that claims anything above 160 Hz is of no problem, but the evidence is inconclusive. We simply don't know enough about these areas to speak definitively. It's clear that the health risks from flicker are typically small for most individuals, but after that it seems so dependent on the sensitivity of the particular viewer that it's hard to lay down hard and fast rules.

I don't have a conclusion for you. Flicker is just another potential hazard to be aware of. What I can say is that *IEEE 1789*, although a not a statute in itself, could be adopted as part of codes. Current Energy Star requirements for LED light sources include a definition and method for measuring flicker (different from *IEEE 1789*) but don't mandate an acceptable level, just that it be reported. The two factions are fighting as to whether a maximum flicker level should be included or not. Watch this space…. ■

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and intellectual property. A 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.